Updates on Soviet Lunar Mission Cartography - Collated Mastodon Postings of Phil Stooke (@PhilStooke)

Between January 2025 and May 2025, Phil Stooke, the distinguished cartographer and author of “The International Atlas of Lunar Exploration” and “The International Atlas of Mars Exploration”, has been sharing a history of the cartography of the Soviet lunar missions via the Mastodon social network.

Rather than leave these postings solely within a single channel, this document has been collated to bring them together into a single document that might be publicly shared by other means.

Collator’s note: The entries recorded here are verbatim copies of the original text and include no alterations. Where an entry prompted a conversation with third parties, those replies have not been replicated here. Each entry is dated and the document runs in chronological order of the date of posting, *not* the date of the mission it describes. Tags have been moved to the date entry as an indication of the mission it refers to. ALT text for the images follows the image as italicized text within boxes,

January 18, 2025

Tomorrow it's time for a new thread. I promised Soviet lunar missions so that's what it will be.

January 19, 2025 - #moon #luna2

I am now going to look at the history of Soviet moon missions. I will not include the large number of failures during launch and flight, just those we can say something interesting about. Luna 1 was the first to get a 'Luna' designation, though not right away. It was called the Cosmic Rocket, and later the First Cosmic Rocket. It was also called Mechta - 'dream'. It missed the Moon and passed into a heliocentric orbit. Luna 2 was not far behind and this one hit the Moon.

January 19, 2025 - #moon #luna2

A very good site for Luna 2 is this by Don Mitchell:

http://mentallandscape.com/L_Luna2.htm

So, we have a spherical shell with several antennae and a magnetometer on a boom. See the trajectory diagram - the trajectory is a plane inclined to the Moon's orbit plane - it's not perpendicular to the orbit plane. Luna 2 and other attempts to do the same thing always approached the Moon from a position north of the orbit and a bit to the right of the Moon's prime meridian.

January 19, 2025 - #moon #luna2

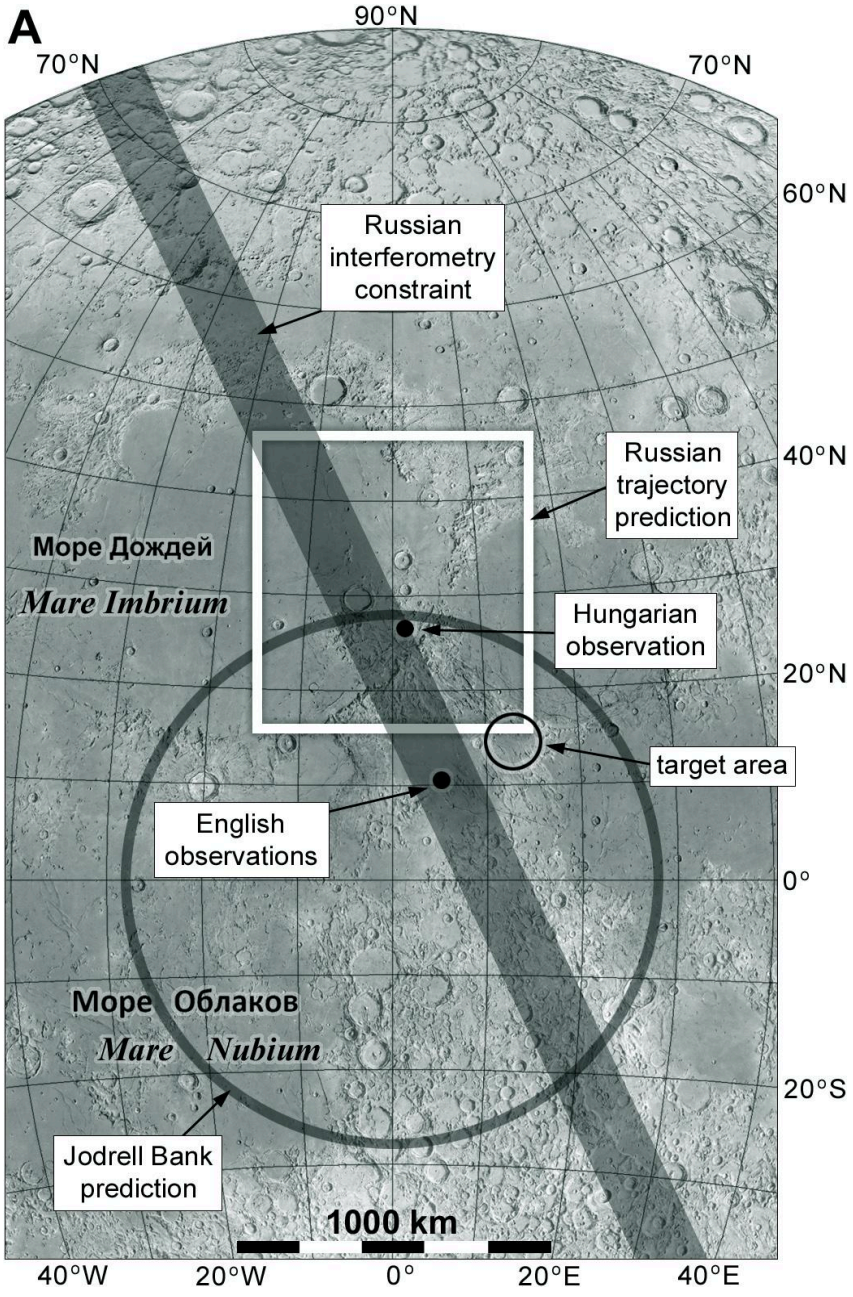
At this stage in lunar exploration the target is just the middle of the lunar disk as seen during approach, basically a bit north and east of the sub-Earth point. The exact point varies with the declination of the Moon (its celestial 'latitude' in Earth's sky), moving south for a more northerly declination, north for the opposite. That website also shows a map of the estimates of impact location. Tomorrow we will look at that in more detail.

January 19, 2025 - #maps #moon #luna2

I linked to Don Mitchell's Luna 2 site, but in a reply Nick Stevens gave a link to his substack, and it's very useful, that post and earlier ones (I really like the space propaganda posters). Well worth a look.

Back to Luna 2 - where did it hit the Moon? Don Mitchell mapped the location constraints, and my map here is only a redrawing of that. Basically there was a target, and tracking suggested the impact was northwest of it, a square on the map…

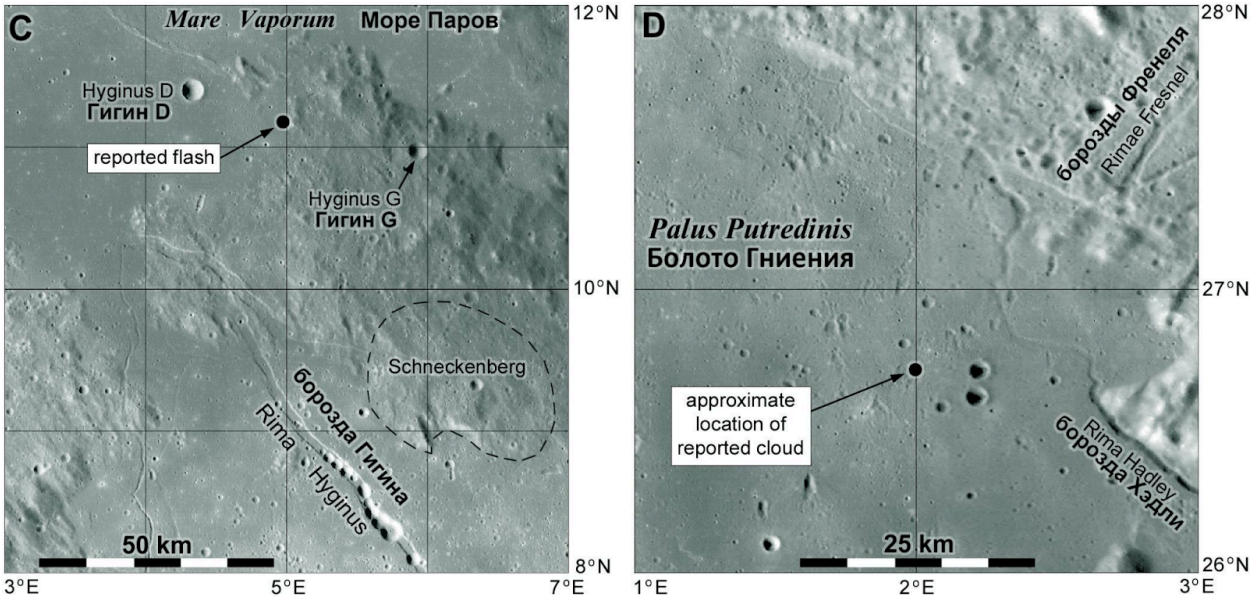
[Image on next page]



A map showing various constraints for the location of Luna 2's impact on the Moon. Tracking suggested a square region 30 degrees north of the middle of the lunar disk. Interferometry suggested he impact was on or near a diagonal line crossing the square. Jodrell Bank placed it within a circle around the middle of the disk. Telescopic observations hinted at impact sites but only one met the other constraints.

January 20, 2025 - #maps #moon #luna2

Jodrell Bank radio telescope data suggested it lay in a circle around the middle of the disk. But telescopic observers looked and might have seen something. Two well-known British astronomers, Patrick Moore and H.P. (Percy) Wilkins, reported seeing something near the Shneckenberg, Moore a flash, Wilkins apparently a dust cloud. Shneckenberg is a 19th Century name, no longer in use, for a hill north of Hyginus with a vaguely spiral appearance - the name means Snail Mountain.



A map showing a reported flash (and possible dust cloud) reported by British astronomers, and a second map showing a place where a Hungarian team saw a dust cloud grow and dissipate. The British observation does not meet the other constraints but the Hungarian one does.

January 20, 2025 - #maps #moon #luna2

Moore and Wilkins saw their events about 90 seconds after the impact, and their location does not match the other constraints. They published their observations in letters to Nature on 15 August 1959. But a Hungarian team at Konkoly sketched an evolving dust cloud in Palus Putredinis near the Apollo 15 site (see Sky and Telescope, November 1960). It fits the other constraints and might be real but observations like this are not universally accepted.

January 20, 2025

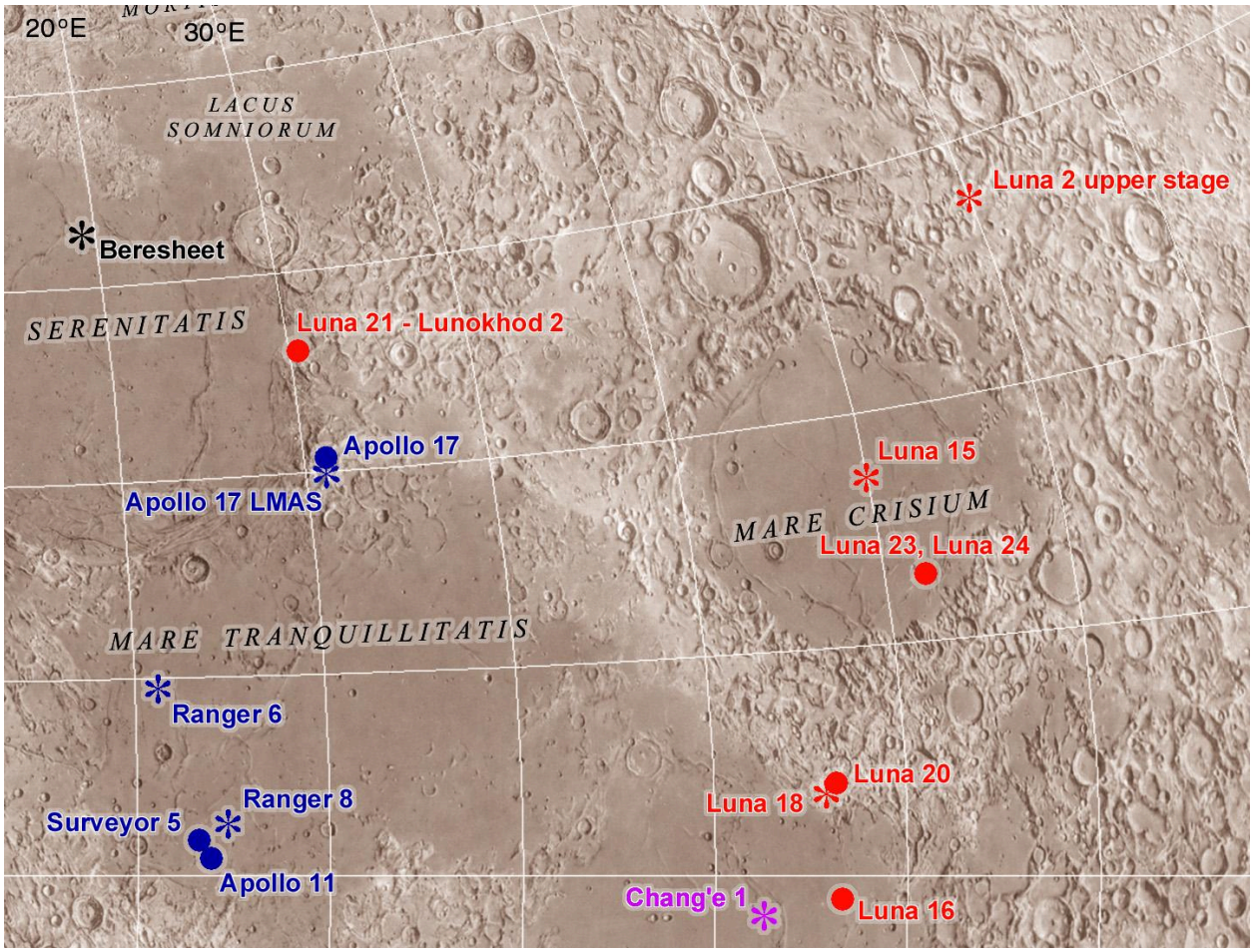
There is one other mystery surrounding Luna 2 that has me perplexed. I have asked veteran Soviet scientists about it, searched all the sources I can think of, to no avail. What is it? Tomorrow all will be revealed.

January 21, 2025 - #moon #luna2

I promised a mystery about Luna 2. I don't know why more isn't made of this but I have not found anyone else who has ever mentioned it. All contemporary sources say that the upper stage pf the launch vehicle hit the Moon 30 minutes after Luna 2. It's on Don Mitchell's page: "...followed by the impact of Block-E about 30 minutes later." But where did it hit the Moon? The second thing ever to reach the Moon - where is it? Can we figure it out?

January 21, 2025 - #maps #moon #luna2

A detailed analysis could be done, but not by me. Maybe someone more capable could try it. I can only make a rough estimate. This is my approach... if the upper stage follows the same vector in space as the probe itself, it hits the Moon displaced from the Luna 2 site by the motion of the Moon in its orbit over 30 minutes. VERY approximately that would put it about where this map shows it. There should be a big circle around that point showing the uncertainty.



Part of a map of the Moon showing landing and impact sites. At upper left is a site labelled 'Luna 2 upper stage'. That point (very uncertain) is where the Luna 2 upper stage may have hit the Moon 30 minutes after the spacecraft impact.

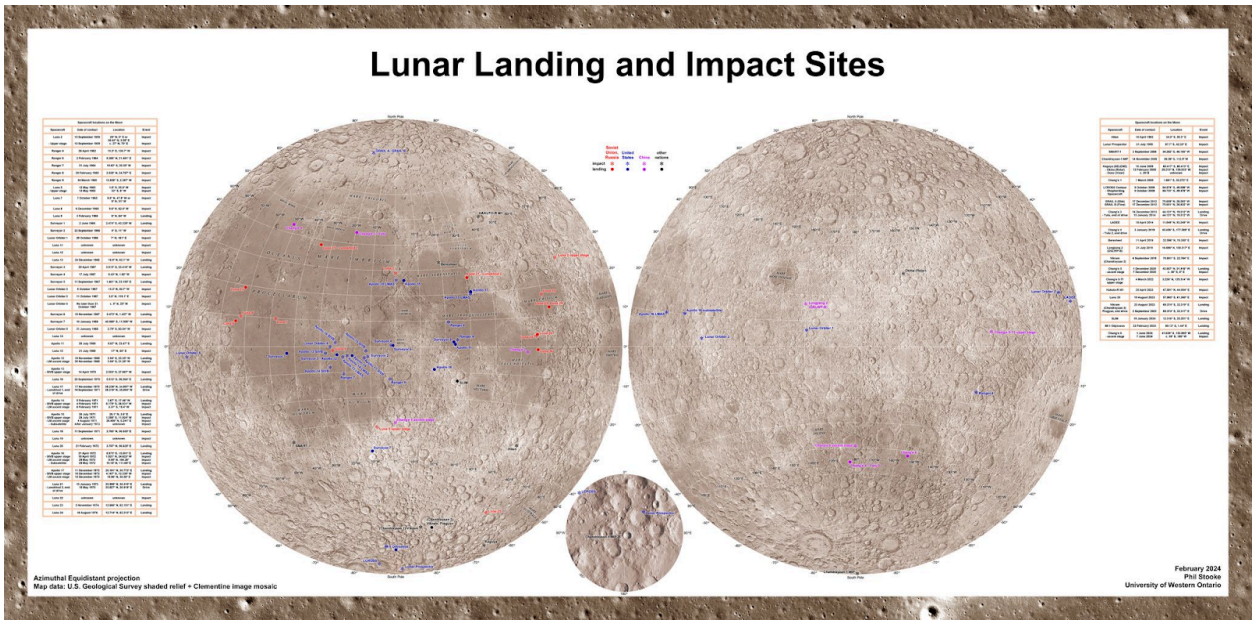
January 21, 2025

Incidentally, that map detail is from here:

https://www.dropbox.com/scl/fi/84muituavs6j2s4th11pc/moon-site-map.jpg?rlkey=yfnhzd8vlpqaeqnv0yxs6llam&dl=0

(A free download of a 30 Mb file).

It is up to date on its details (including Chang'e 6) but I forgot to revise the date in the lower right corner. I will be updating this soon! - Firefly's Blue Ghost Mission 1 will try to land near Luna 15's impact site on 2 March 2025.



January 22, 2025 - #moon #luna3

We move on to Luna 3. See its images of the far side of the Moon here (top of this page):

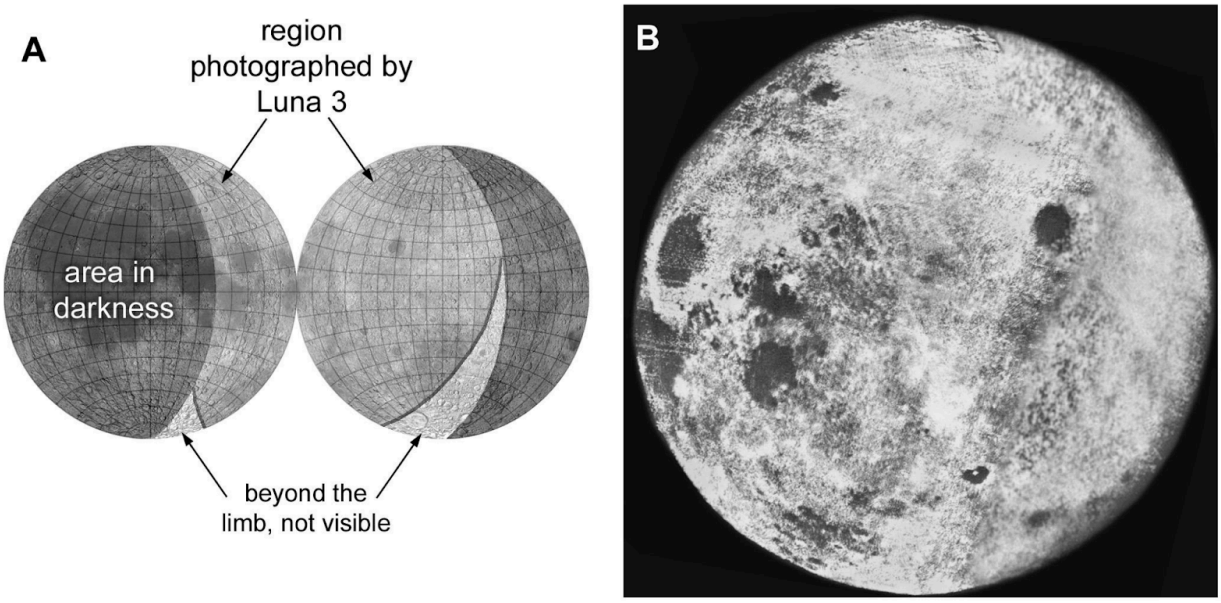
http://mentallandscape.com/C_CatalogMoon.htm

(another of Don Mitchell's pages. He has done important work finding and preserving these images.)

The pictures look primitive but this was 1959, and words can hardly express the audacity of the engineers who designed, built and operated the spacecraft. This was the first time anything like this had ever been done.

January 22, 2025 - #moon #luna3

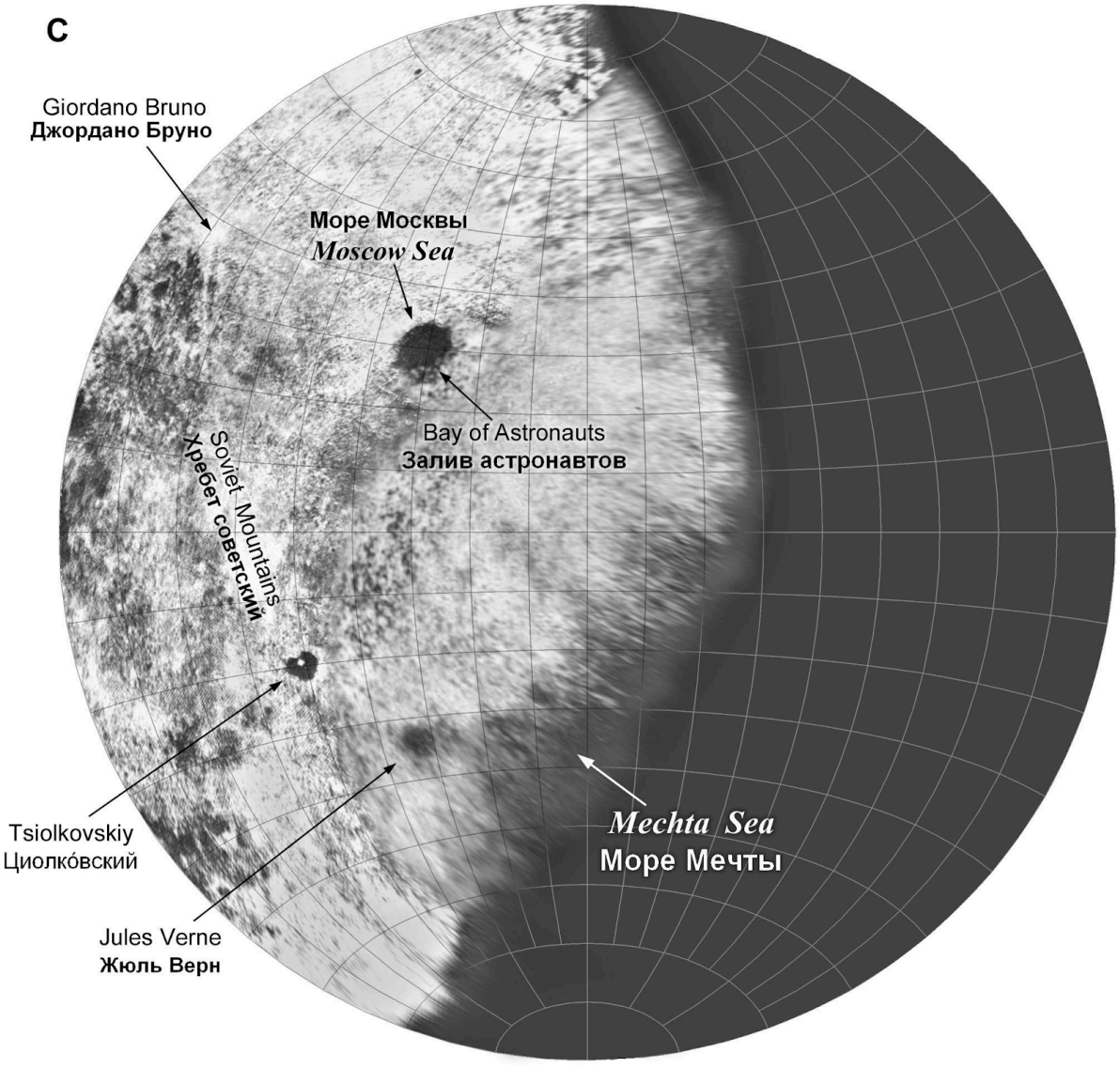
This shows the area covered by the images and a cleaned-up mosaic of good bits of individual images. Vladislav Shevchenko at Sternberg gave me a copy of the original atlas published to document the mission. Several maps were made by different groups but obviously it was not easy to interpret many of the markings revealed in the images. But the scarcity of dark lava flows was immediately apparent.



The area of the Moon covered by Luna 3 images is shown in a map in two hemispheres - earth-facing side and far side of the Moon. A second image at right is a cleaned-up mosaic of good parts of the various images, omitting as many artifacts as possible. It shows a full phase, 70% of which is on the far side. A few dark spots are visible - lava flows.

January 22, 2025 - #maps #moon #luna3

This map was also part of my 'exploring the farside' series from many months ago. It shows the Luna 3 mosaic projected onto an azimuthal grid for the far side. A big chunk was still not mapped. Some names were given and they include the Moscow Sea - still used now - and Bay of Astronauts (Zaliv Astronavtov). The word Cosmonaut was not yet in use.
Tsiolkovskiy is also still used. Mechta Sea commemorates Mechta (Luna 1). It's still used on Russian maps.



THe Luna 3 mosaic of the far side of he Moon is here projected into map coordinates for an azimuthal projecion of the far side. A few features are named and some of the names are still used today.

January 23, 2025 - #moon #luna5

Several American Pioneer probes were intended to take pictures of the farside but failed. Two other Soviet missions in 1960 were supposed to fill in the gap on the farside but failed. Luna 4 was intended to land but it missed the Moon. The next Soviet contact with the Moon was Luna 5. It was intended to land but it crashed. But where? This site:

https://en.wikipedia.org/wiki/Luna_5

says "The place of impact was first announced as 31°S 8°W ... but later it was estimated as 8°N 23°W"

January 23, 2025 - #moon #luna5

This should be more authoritative:

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1965-036A

It says:

"A Soviet announcement gave the impact point ... roughly 31 degrees S, 8 degrees W. Later analysis gives a location of 1.35 S, 25.48 W ... (Other analyses and reports give a wide range of possible impact sites: 1.6 S, 25 W; 8.17 N, 23.43 W; 30 S, 8 W; and 31 S, 8 W.)"

What is going on? How can there reports be so varied? Is there a Russian source to go to?

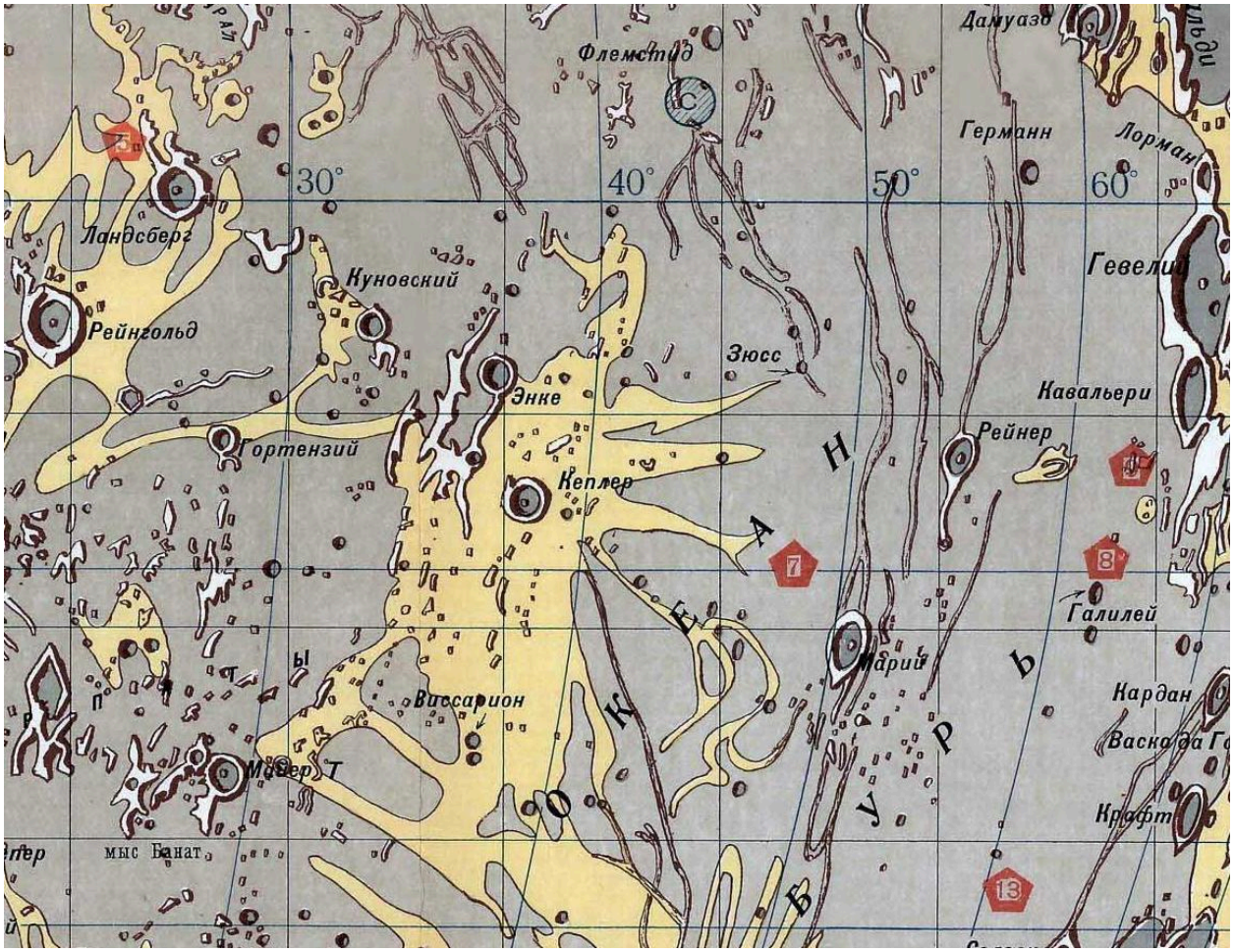
January 23, 2025 - #moon #luna5

Leonid Ksanfomality published the paper 'Luna-5 (1965): Some Results of a Failed Mission to the Moon' in Cosmic Research in 2018. It describes photographs of a dust cloud taken at an observatory in the Georgian SSR, interpreted as the impact event at 1.35° S, 25.48° W. That's the 'later analysis' position in the previous post. Photos should be conclusive ... maybe ... but reports like this are not always accepted.

January 23, 2025 - #maps #moon #luna5

There seems to be a reasonable case for saying the impact was near the equator and about 25 west. This Soviet era map shows the site. It's south up. At top left is a red symbol with '5' in it, near the crater Lansberg. Other Soviet landers are at lower right (9 and 13 succeeded). At top centre is a blue circle with a 'C' - that's Surveyor 1.

Somewhere around that point should be the Luna 5 site. But what about those points around 30 south? The mystery continues tomorrow.



A Soviet-era map (with south at the top) showing the location of Luna 5 (top left) and other Luna landers at lower right. The Luna 5 location roughly matches some of the coordinates given for the mission. But it's not the whole story.

January 24, 2025 - #moon #luna5

I have made a big deal about this confusion over the location of the Luna 5 impact. It is going to be a familar story. We don't know where Luna 7 crashed, or Luna 15. You can find coordinates... but more than 1 set, so it doesn't help very much.

What about this 30 south location for Luna 5? How can it be so far off the other location? Turns out it's not the same object, though many accounts don't explain that.

January 24, 2025 - #moon #luna5

NSSDCA says this:

"... the astronomical observatory at Rodeswisch in Germany took photographs of the area which showed a cloud of dust. The cloud was 80 km by 203 km in extent at 19:15:24.7 UT and the center was estimated at 31 S, 8 E."

OK, first - 8 east? The other southern sites were about 8 west. This is not about confusing 2 places, it's about confusing old and new longitudes for the same place. East and west were switched in 1960 so they corresponded to our east and west.

January 24, 2025 - #moon #luna5

Next issue - 80 by 200 km? That's huge - you would only really expect 5 or 10 km for an impact dust cloud of this scale. IF - and it's a giant IF - this was a real observation, it suggests that a significant amount of residual fuel vaporised to lift and spread dust, not just ballistic ejection of dry regolith. This doesn't say something an article in New Scientist in 1965 (vol. 46, p. 842) did say... this southern impact was the launch vehicle upper stage rocket.

January 24, 2025 - #moon #luna5

Yes, a different object. You can read more about it here:

https://www.alpo-astronomy.org/content/Lunar/Publications/TLO/2023/tlo202307.pdf

(see pages 73-75).

I hope you can see from this that there are plenty of things we still don't know about these Soviet missions.

I'm trying to attach a picture but getting error messages. I will do it tomorrow.

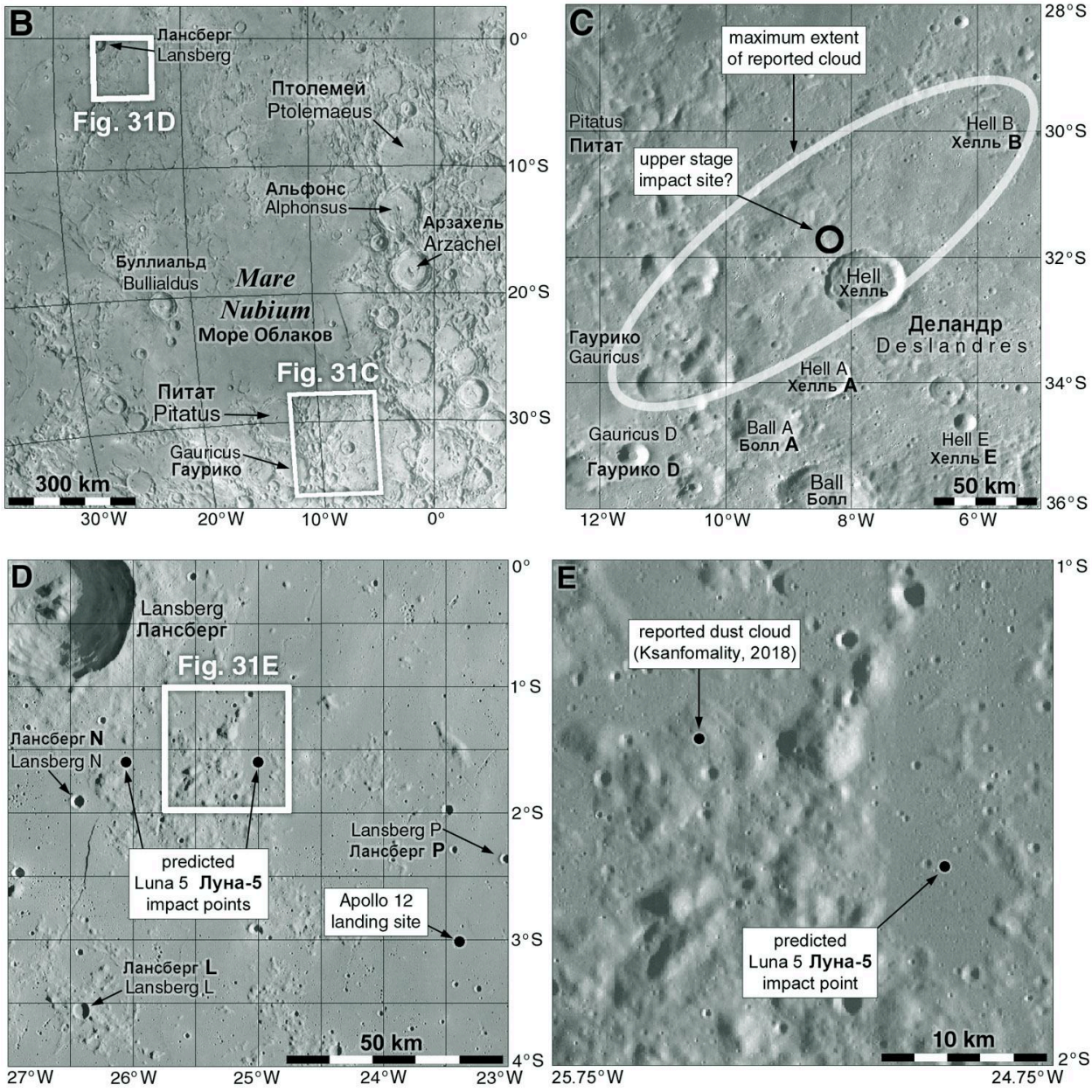
January 25, 2025 - #maps #moon #luna5

This was the picture I couldn't post yesterday when Mastodon.social had the collywobbles.

At top left is a context map showing two areas apparently containing crashed Luna 5 hardware. Top right: the location of a large dust cloud apparently photographed - and reported to be the impact site of Luna 5's upper stage rocket. Bottom, 2 maps zooming in on the area where Luna 5 itself apparently crashed.

Luna 6 was supposed to land but missed the Moon by a wide margin.

(Image on next page)



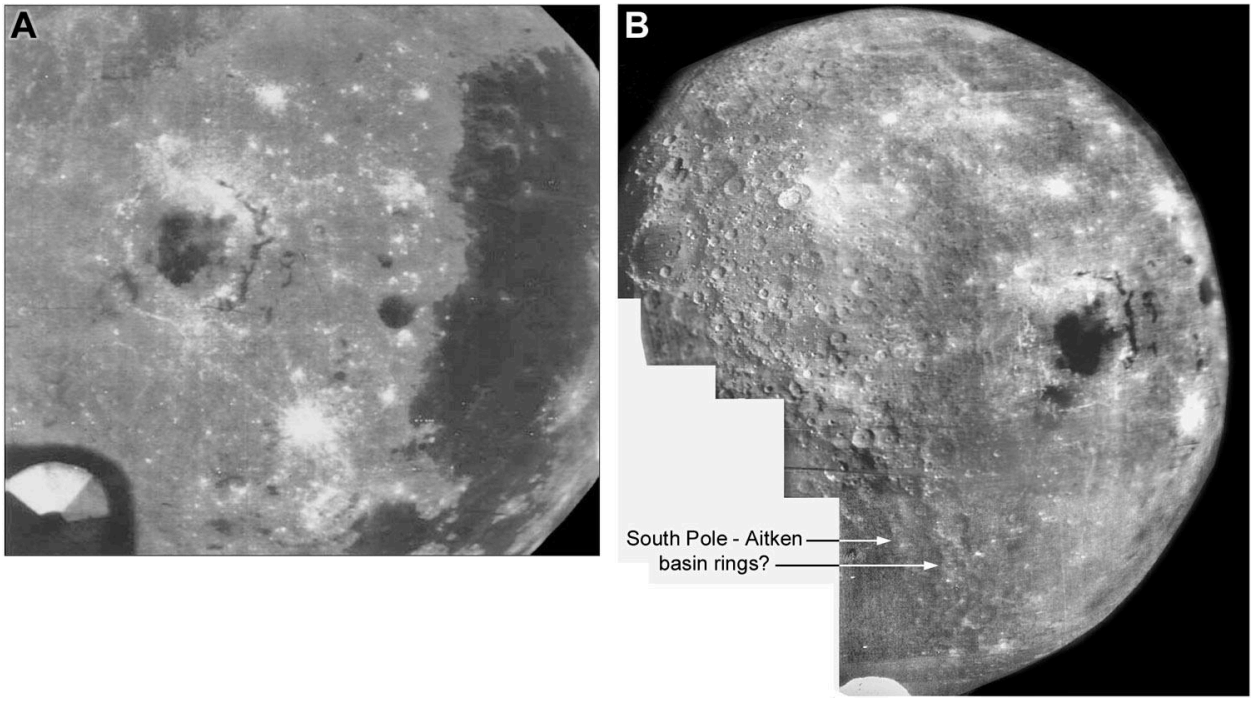
Four small maps illustrating the locations mentioned for Luna 5 on the Moon. At top left is a context map showing two areas apparently containing crashed Luna 5 hardware. Top right: the location of a large dust cloud apparently photographed - and reported to be the impact site of Luna 5's upper stage rocket. Bottom, 2 maps zooming in on the area where Luna 5 itself apparently crashed.

January 26, 2025 - #moon #zond3

Luna 6 missed the Moon, and the next lunar mission to provide useful data was not a Luna but Zond 3. It's a bit of a misnomer to call it a lunar probe. The early Zonds were planetary probes, sent to Venus and Mars. Zond 3 appears to have been a companion to Zond 2, the Mars probe, which failed during the cruise to Mars (and may have hit the planet, though all sources say it flew by at 1500 km altitude. Truth is, we don't know, and I might go back to this in future)

January 26, 2025 - #moon #zond3

Zond 3 was apparently supposed to go to Mars but some technical problem delayed it until Mars was not reachable, so it was launched on a lunar flyby trajectory (which then took it out to the orbit of Mars but not near the planet). The lunar flyby enabled imaging to fill much of the gap left by Luna 3. Here is a single image and a mosaic of images. These were shot on film, processed, scanned and transmitted like Luna 3 images.



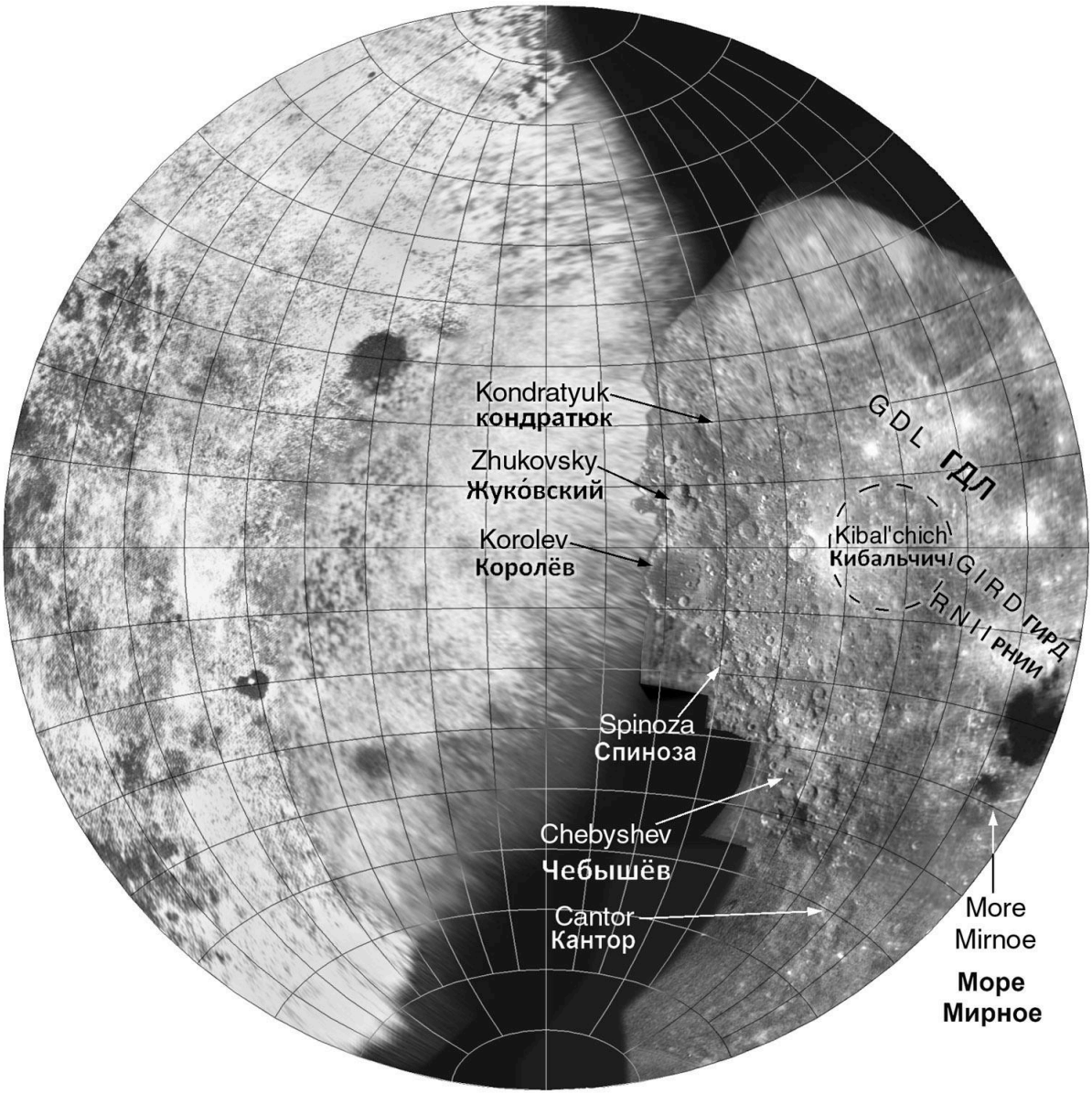
An image from the Soviet Union's Zond 3 spacecraft in 1965 (left) and a mosaic of all Zond 3 images (right). They cover some of the far side not seen by Luna 3.

January 26, 2025 - #moon #zond3

I point out some very poorly seen structures which might be South Pole-Aitken basin rings. The SPA basin rim is better preserved in this area than elsewhere. Nobody seems to have claimed this in the past and I may be over-interpreting (I do that a lot). The big dark spot is Mare Orientale, the Eastern Sea which is on the west side of the Moon as seen from Earth - because of that change in east-west coordinates I mentioned earlier.

January 27, 2025 - #moon #zond3

The new Zond 3 images allowed for new mapping. Kira Shingareva herself drew a shaded relief map of the Hertzsprung basin, and Lipsky et al. constructed the 'first complete map of the Moon' (missing only polar regions of the farside). First, here is my composite of Luna 3 and Zond 3 images on a map of the farside, with some names added. The basin called Korolev still has that name. His identity was secret until his death not long after this mission.



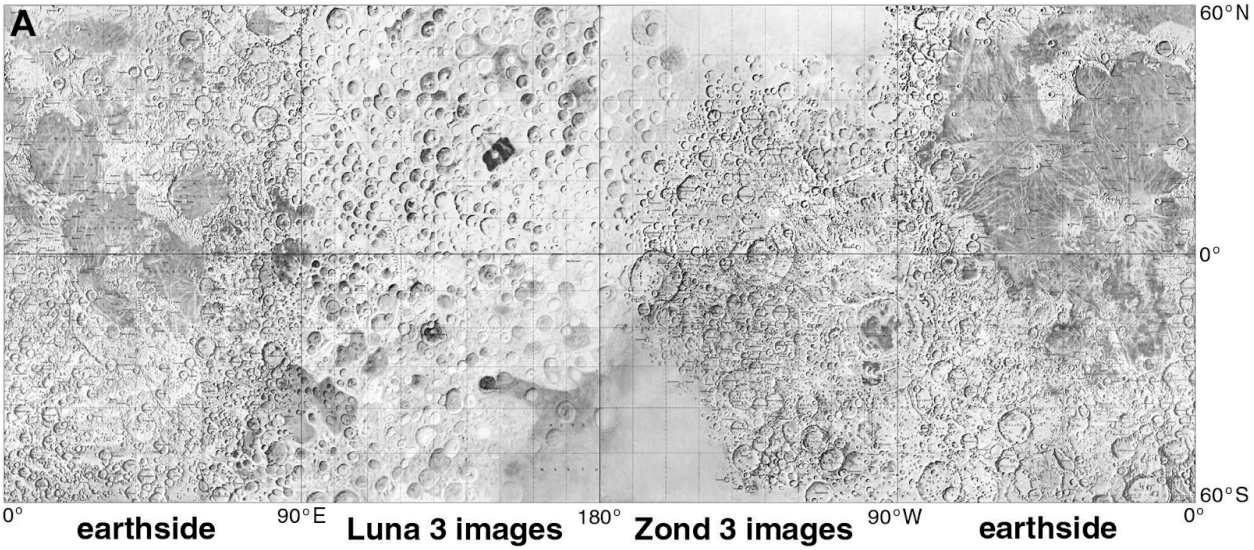
A map of the Moon's farside consisting of Luna 3 images (left) and Zond 3 images (right). A few names are added, notably Korolev for a large basin which still carries that name.

January 27, 2025 - #moon #zond3

GDL, GIRD and RNII were the big rocket research institutes. The names are given to giant crater chains made by ejecta from the Orientale basin. More Mirnoe (Peaceful Sea) is a dark ring SW of Orientale, un-named now but considered to be a volcanic plume deposit around a central vent, similar to some of those on Jupiter's moon Io. It's the only ring deposit on the Moon.

January 27, 2025 - #maps #moon #zond3

Here is a greatly reduced copy of the First Complete Map of the Moon. The farside is in the middle with half the nearside (facing Earth) at each end. Here, each fuzzy spot in the Luna 3 area is drawn like a crater, which is a severe over-interpretation of the images. Only a few months later the Lunar Orbiters started filling in details more clearly (see the farside mapping thread).



January 28, 2025 - #moon #luna7

Next up in our story of Soviet lunar missions is Luna 7. This was another landing attempt - Lunas 4, 5 and 6 were landers too - but success still eluded Korolev and his team. Luna 7 crashed, but as with Luna 5 there are several possible places in the records. NSSDCA says " it impacted the lunar surface at roughly 9 N, 49 W (also given as 9.8 N, 47.8 W)". The first location is from Johnson, N. L., Handbook of Soviet lunar and planetary exploration, 1979.

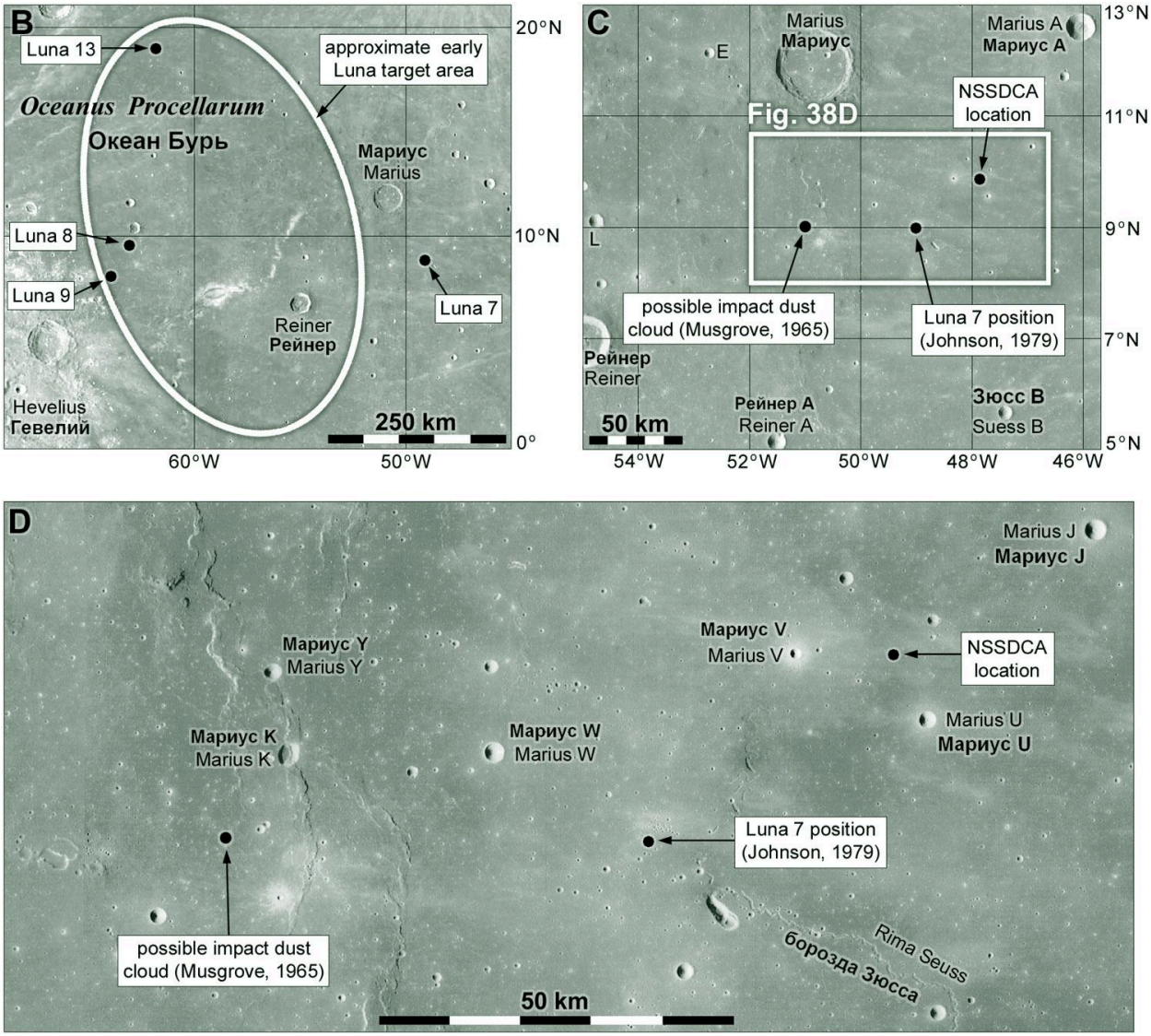
January 28, 2025 - #moon #luna7

These maps show (top left) the general target region for these landers (each had its own smaller target within the ellipse), (top right) the Luna 7 region and (below) a zoom in to the area. There is a third place marked, taken from:

Musgrove, R. G., 1965. Microdensitometer analysis of Luna 7 impact. MSC Internal Note no. 66-ET-3, 15 Dec. 1965.

This is one of those things you only see if you poke around in archives. It concerns an image taken at the Pic du Midi observatory... #moon #Luna7

Image on following page.



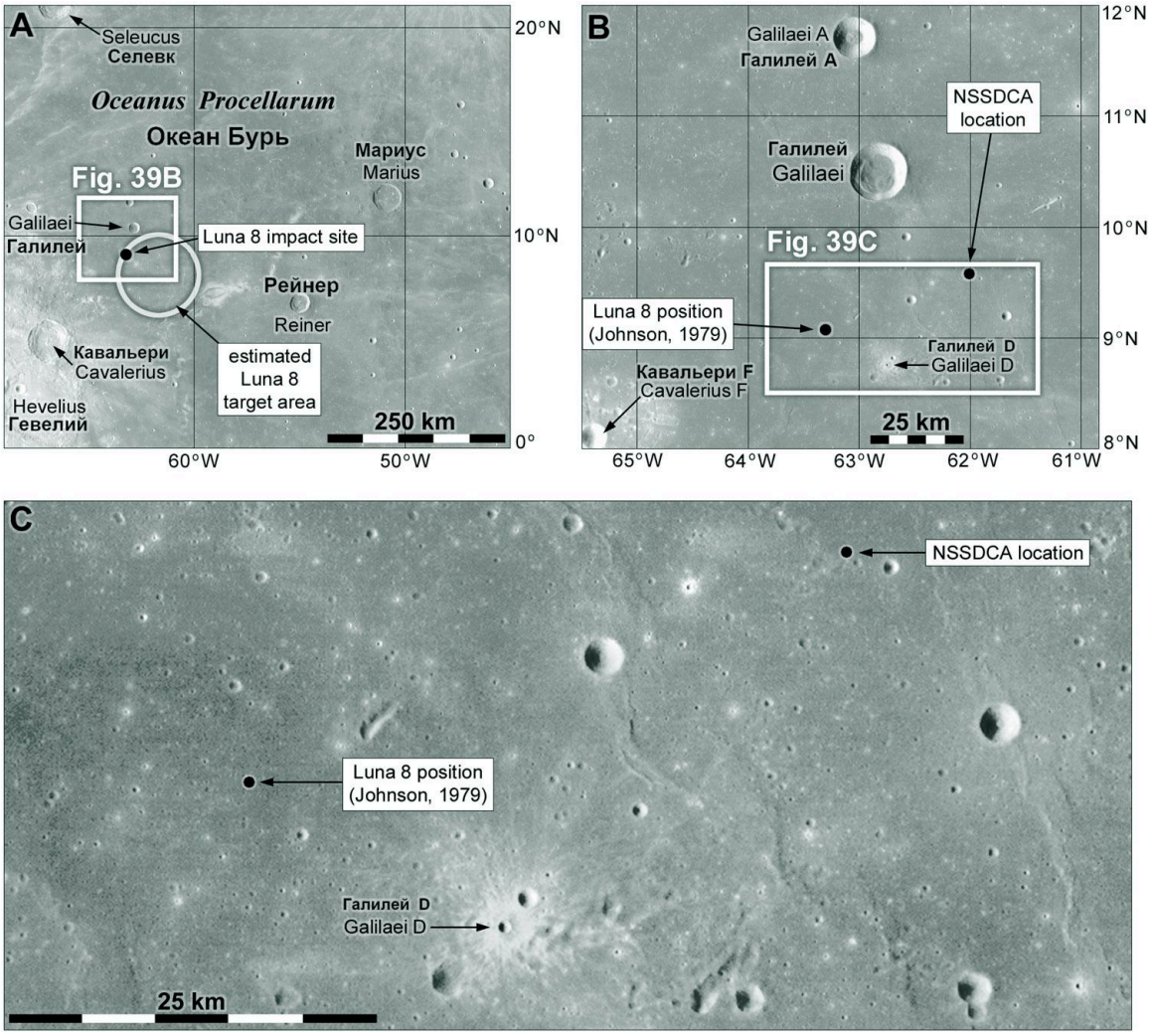
Top left: a map of the general target area for early Soviet Luna landers. It is a big ellipse in west central Ocanus Procellarum. Top right: the Luna 7 impact area, and below, a closeup of that area. 3 possible locations are shown for Luna 7.

January 28, 2025 - #maps #moon #luna7

... a picture taken to see if anything would be visible. It might show a dust cloud but observations like this are not widely accepted (image artifacts are common). MSC is the Manned Spacecraft Center, now the Johnson Space Center south of Houston. Luna 7 is another example of a location we do not have reliable information for (and therefore is effectively impossible for us to find in LRO images). Korolev was getting closer but his clock was ticking.

January 29, 2025 - #maps #moon #luna8

We move on to Luna 8, which got close to landing safely. In my old Moon book and new things I am working on now I wrote "The NSSDCA position is 9.6 N, 62.0 W in western Oceanus Procellarum but Johnson (1979) gives 9.13 N, 63.30 W " (edited a bit) - but now I see that NSSDCA has dropped its position and adopted the one from Johnson. Now I have to go back and make changes in various things I have been putting together... Anyway, these maps sum it up.



3 maps which locate the Luna 8 impact area on the Moon. At top left is a context map showing the region with a crcle indicating the probable target area, a patch of ray-free lava flows in Oceanus Procellarum. At top right is an enlargement showing two possible areas for this impact. The area is enlarged below. The site at right was given by the NSSDCA but has now been dropped in favour of the other site.

January 29, 2025 - #moon #luna8

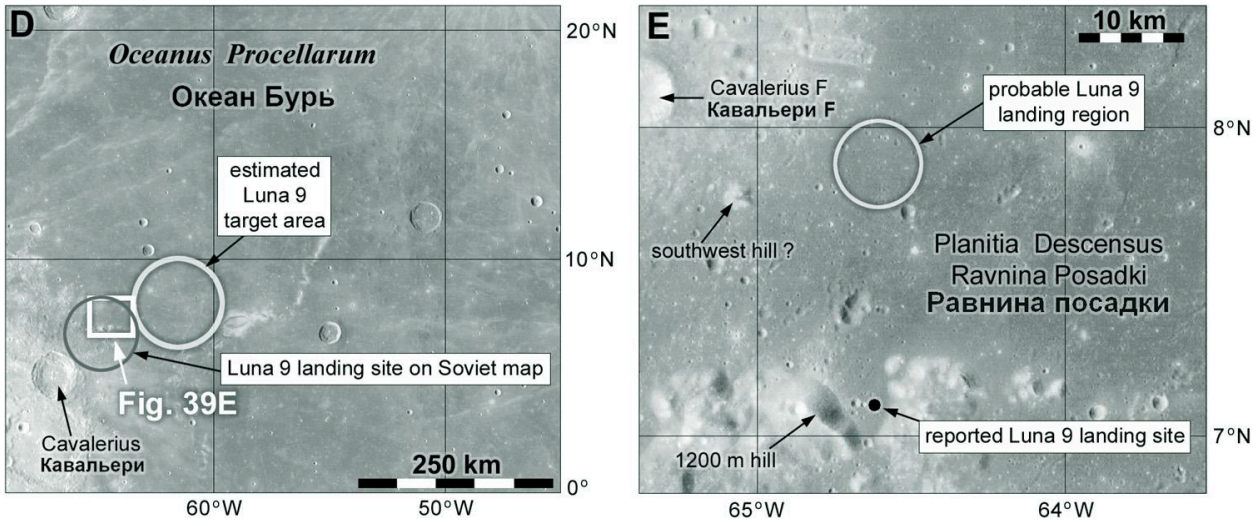
This was the last flight observed by Sergei Korolev before his unexpected death during surgery in January 1966. Korolev is still revered in Russia. One senior lunar scientist was proud to be able to say 'I was hired right out of university by Sergei Pavlovich', a mark of honour. Next - a landing finally works!

January 30, 2025 - #moon #luna9

Luna 9 succeeded where several previous attempts to land had failed. Sadly, Korolev did not live to see it. You would think we would know where such an important site was, but as with these other sites, we do not. NSSDCA says:

"west of Reiner and Marius craters at approximately 7.08 N, 64.37 W"

These maps show that location. But it must be wrong. The first map shows the estimated target area (ray-free lava flows) and a circle around the landing site.



Two maps of the Luna 9 landing site. At left, a context map showing the landing area with a circle showing the suggested target and another showing how the site was illustrated in a Soviet release. At right a closer view showing the usually quoted location among some hills, and a more likely area in plains further north.

January 30, 2025 - #moon #luna9

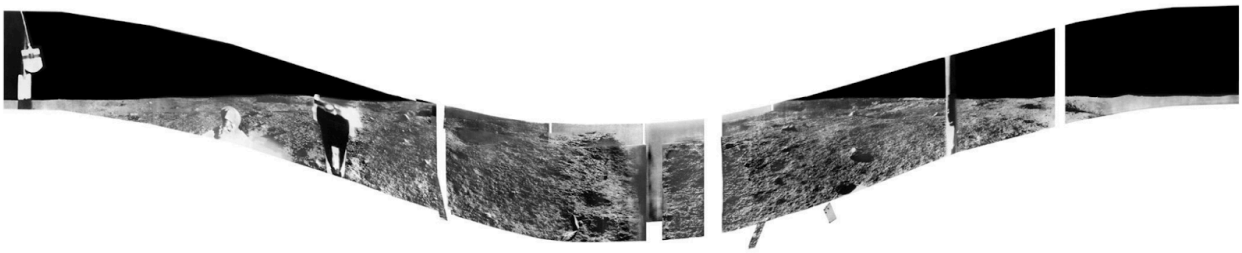
That circle was from a map I received from the Soviet Embassy in London, UK when I was a teenager. The coordinates were only the middle of a roughly 50 km radius circle containing the site, never intended as an exact location. We know for sure that Luna 9 is not at that 'reported site' because it lies between 1000 m high hills and Luna 9 saw a flat horizon. Simple as that. So where is it? I put it further north - a rough estimate only.

January 30, 2025 - #moon #luna9

We will see the horizon later. The site has to be far enough from the hills that the c. 60% of the horizon we can see (from south to west to north) is almost completely flat. If the Moon was a perfect sphere except for those hills we could calculate where they cannot be seen from. But it's not. Even a small local topographic rise could hide the hills when viewed from far away, so we can't easily guess. Many have searched for it without success.

January 31, 2025 - #moon #luna9

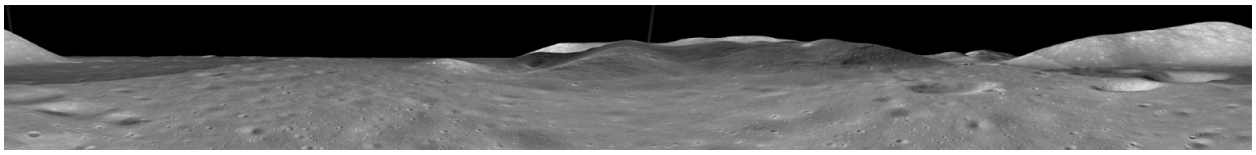
I am going to examine the panorama in detail later, but here is a quick look at it at reduced resolution. It has been roughly projected to make the horizon level - the scanning camera axis was tilted down towards the east and up towards the west. We can see about 65% of the horizon from south to west to north. In this view east is in the middle, west at the ends. The horizon is flat.



The Luna 9 panorama projected to make the horizon level, with east in the middle and west at each end. The panorama was taken with a tilted scanning camera giving a sinusoidal shape to he panorama.

January 31, 2025 - #moon #luna9

The usual quoted coordinates are in a valley between prominent hills. We can reconstruct a panorama from that location using LRO images and topography. Here is the result. Again, east is in the middle. Sharp brightness changes are from the original LRO mosaic. The largest hill, due west of the supposed landing site, would be very prominent. The lander can not be at that location.



A synthetic panorama from the usually cited location of Luna 9. East is in the middle. The big hill would be in the Luna 9 panorama. It's not so the lander cannot be at that location.

February 1, 2025 - #moon #luna9

Let's look at the panorama transmitted by Luna 9, the first view we ever had on the lunar surface. Actually it's 3 panoramas, taken over 2 earth days, with the lander shifting a bit between them, possibly slipping on a slope. See them here:

http://mentallandscape.com/C_CatalogMoon.htm

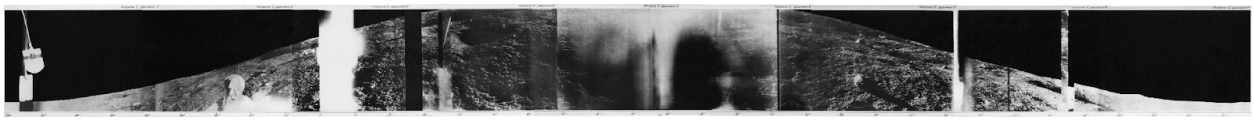
(Don MItchell again) - look about 20% of the way down the page.

Here is a translation of a Soviet paper on the pictures:

https://ntrs.nasa.gov/api/citations/19670002910/downloads/19670002910.pdf

February 1, 2025 - #moon #luna9

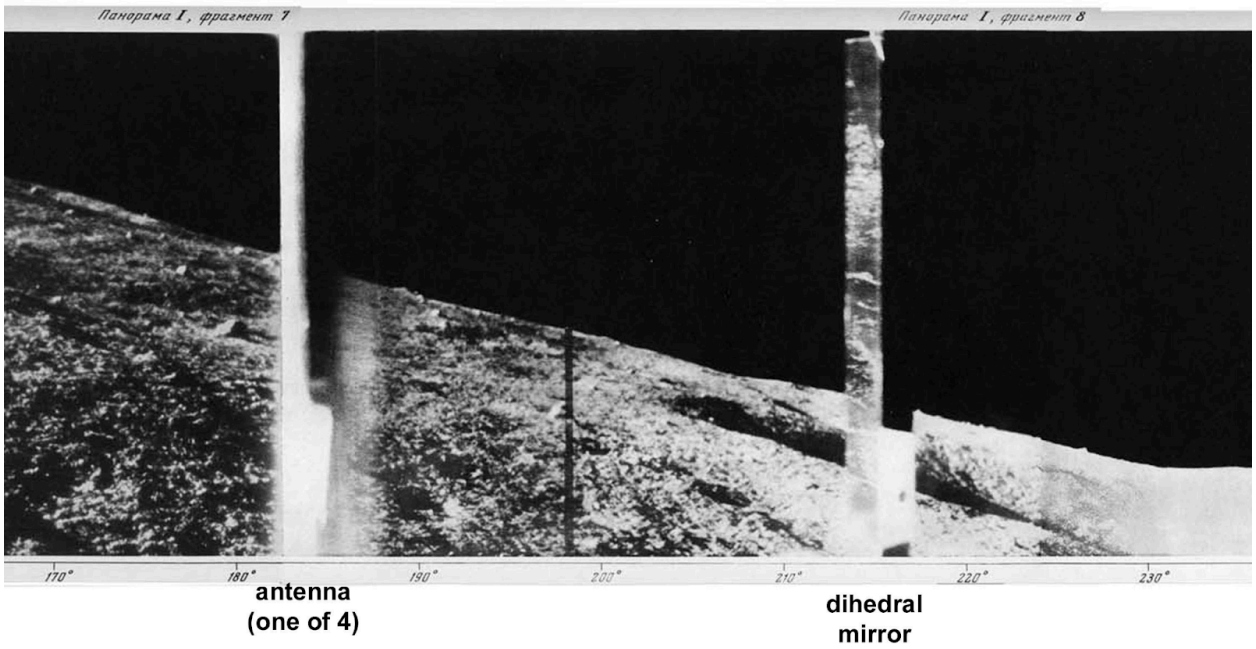
Here, taken from Don Mitchell's site, is panorama 1. There is plenty to say about it. At left is a hanging photometric target. In the middle a big section is washed out by glare - the Sun is only just above the horizon and outside the frame. Panorama 3 fills it in for us - the Sun is higher in the sky. We can see some vertical structures, which we can see better in an enlargement (next post).



The first of 3 panoramas from Luna 9, the first views ever taken on the Moon. It was taken with a scanning camera and spans an entire 360 degrees. The camera is tilted down in the middle and up at the ends, and the middle bit is washed out by glare from the low early morning sun.

February 1, 2025 - #moon #luna9

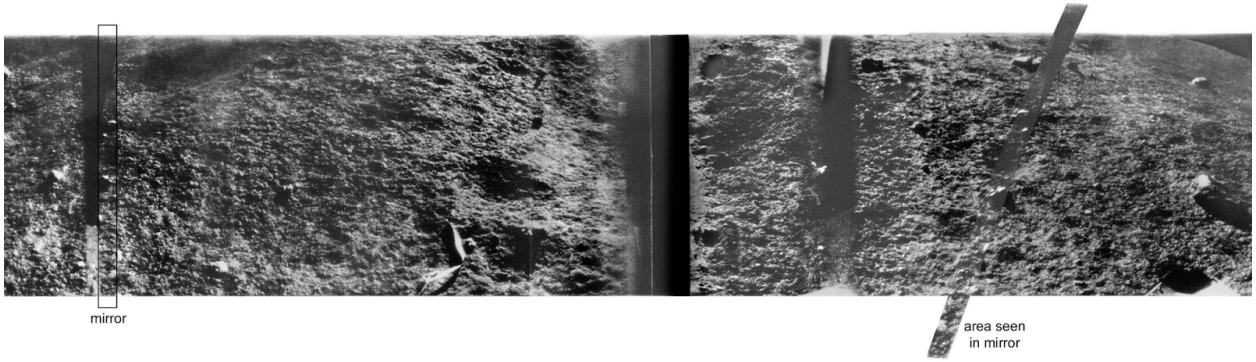
Here is a section from the right side of the panorama. At left is an antenna - pictures of the lander show it had 4 of these. At right is a dihedral mirror - a two-sided mirror. Each of its sides reflects a narrow strip of the surface, and if we search for the area viewed in the mirror we can see a bit of the surface from 2 directions and get some topographic information. There were 3 of these.



An enlargement of part of the Luna 9 panorama showing an antenna and a two-sided mirror. The mirror reflects strips of two areas off to its sides and some of them can be identified.

February 2, 2025 - #moon #luna9

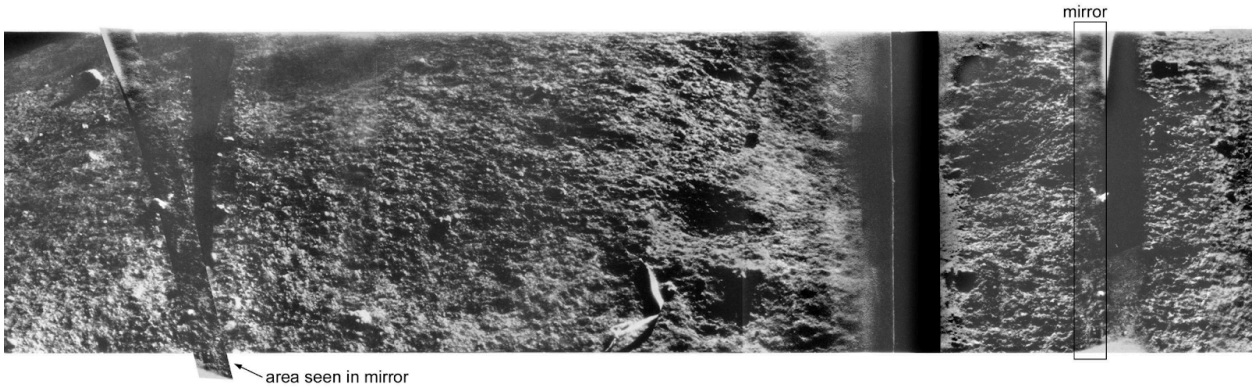
Here is part of Luna 9 panorama 3 from the site I linked to. It's the middle section, showing how the part that was not seen properly in panorama 1 is seen clearly here. At left I point out one of the mirrors (one half of the dihedral mirror). If you didn't know it was a reflection it would look the same as the surrounding surface. At right is the area it is reflecting (the mirror section copied, pasted, flipped and registered with the base). Fun with Photoshop.



Part of Luna 9's third panorama. At left a box highlights a small mirror (half of a double or dihedral mirror). At right is the place on the surface which was viewed in that mirror.

February 3, 2025 - #moon #luna9

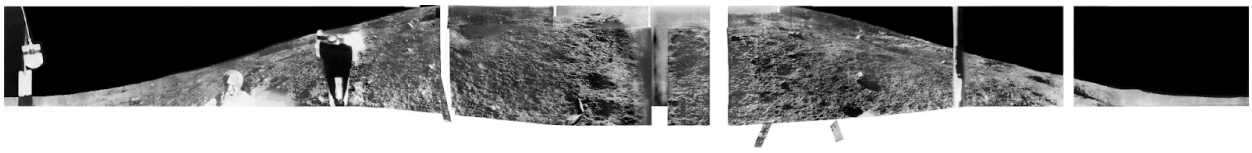
Here is another example of the same thing from Luna 9 panorama 3. I don't know how useful this was, and it was not attempted again, but it makes for an interesting exercise in image manipulation.



A second example of a Luna 9 panorama with a mirror outlined at the right and the area seen in it at left.

February 3, 2025 - #moon #luna9

Luna 9 took 3 panoramas, shown on the earlier link. They can be combined to make the image shown here. Panorama 1 (the only one with the horizon at each end) is the base. Bad bits in it have been replaced with better bits from the other panoramas. The lander tilted down between panoramas, either from settling in loose soil on a slope or from thermal expansion of its fold-out 'petals'. I cut out the mirrors since they block the scene behind, and added 3 sections seen in the mirrors. #moon #Luna9



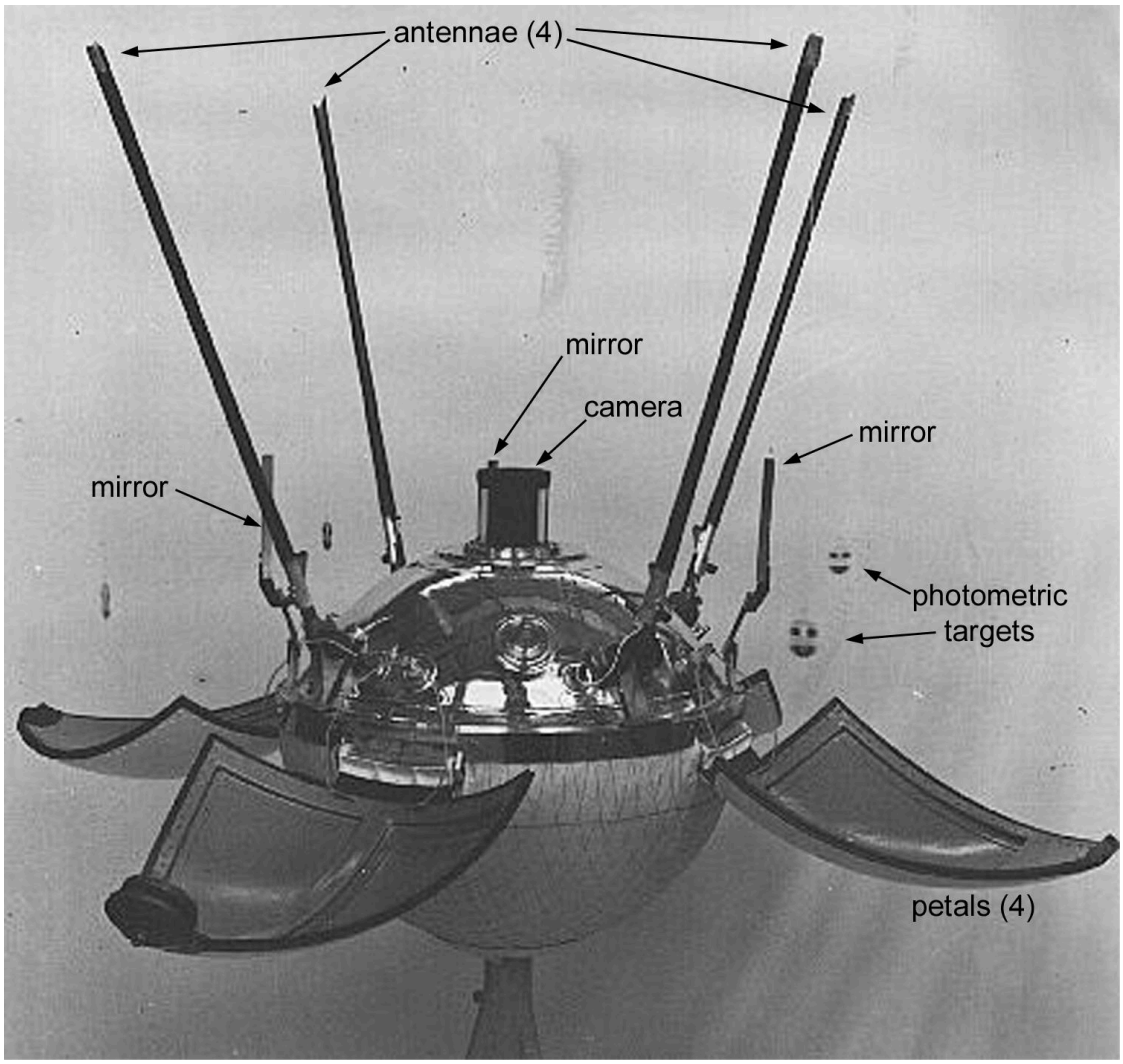
A composite of all three Luna 9 panoramas using bits of each panorama to fill in gaps or bad bits in other panoramas. Movement of the lander and changing sun angles and glare make process complicated.

February 3, 2025 - #moon #luna9

Go here to read about the mission and to see images of the lander:

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1966-006A

Here is one of those images, annotated. The 4 antennae should be visible in the panorama. One is behind the hanging targets at left. The rest are equally spaced - one is in the middle, one at mid-right clearly seen. There should be one at mid-left but its place is taken by a black object. It seems to be the base of an antenna which did not deploy properly.



Annotated image of Luna9 showing the near-spherical lander with its 'petals' open (they would automatically push it upright if it came to rest on its side). 4 antennae stick out of the top, three mirrors are visible and the camera on top.

February 3, 2025 - #moon #luna9

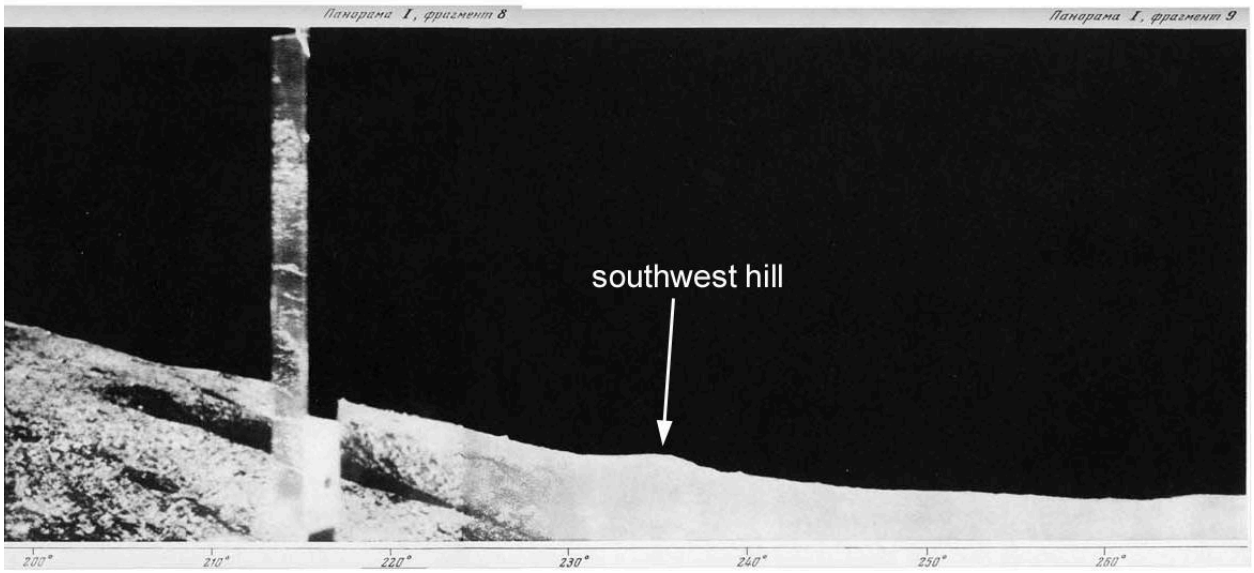
One final question remains - where it it? All will not be revealed because we don't know, but we will look at the problem tomorrow.

February 4, 2025 - #moon #luna9

Time to consider where Luna 9 is. My first map for Luna 9 shows the location of the NSSDCA coordinates, which come from Soviet estimates: 7.08 N, 64.37 W. From my map you might think it looks more like 64.7 west - that shift is caused by better map control today. In 1966 those coordinates would put you in that gap between hills. My map uses modern coordinates but I have moved my point to be in the right place in the landscape. You can't just assume 1960s coordinates are reliable.

February 4, 2025 - #moon #luna9

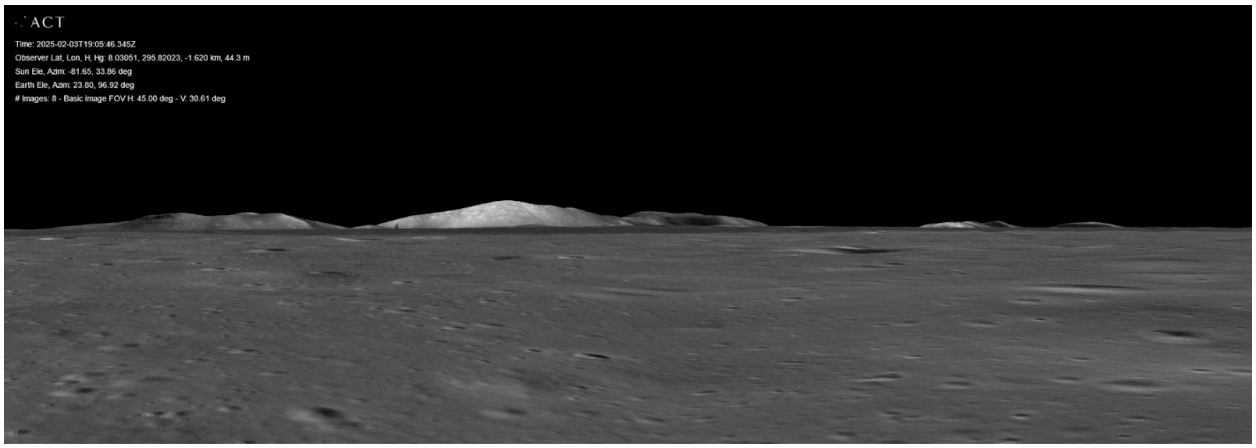
I already pointed out Luna 9 can't be between those hills because they would be visible on the horizon. For years I have argued that Luna 9 has to be further north, as my map suggested, so the hills are over the horizon. A small hill is visible on the southwest - as shown here. I though it might be visible on a map to give another clue. But is it nearby and small or distant and big? There's no way to tell. I show the hill and a suggested location in that earlier map.



Part of a Luna 9 panorama showing a small hill, 'southwest hill'. Is it visible on maps? But we don't really know if it's small and near or big and distant.

February 4, 2025 - #moon #luna9

I never really tested that assumption. Recently I have revisited the issue with a new tool, the Quickmap synthetic panorama tool. I can make a panorama for any location. Surprise - you have to go quite far north to lose those hills and then there is no good candidate for 'southwest hill'. This is from 30 km north of the map site. But I noticed that the largest hill in that range starts to look the the SW hill if you get far enough away and the other hills are below the horizon.

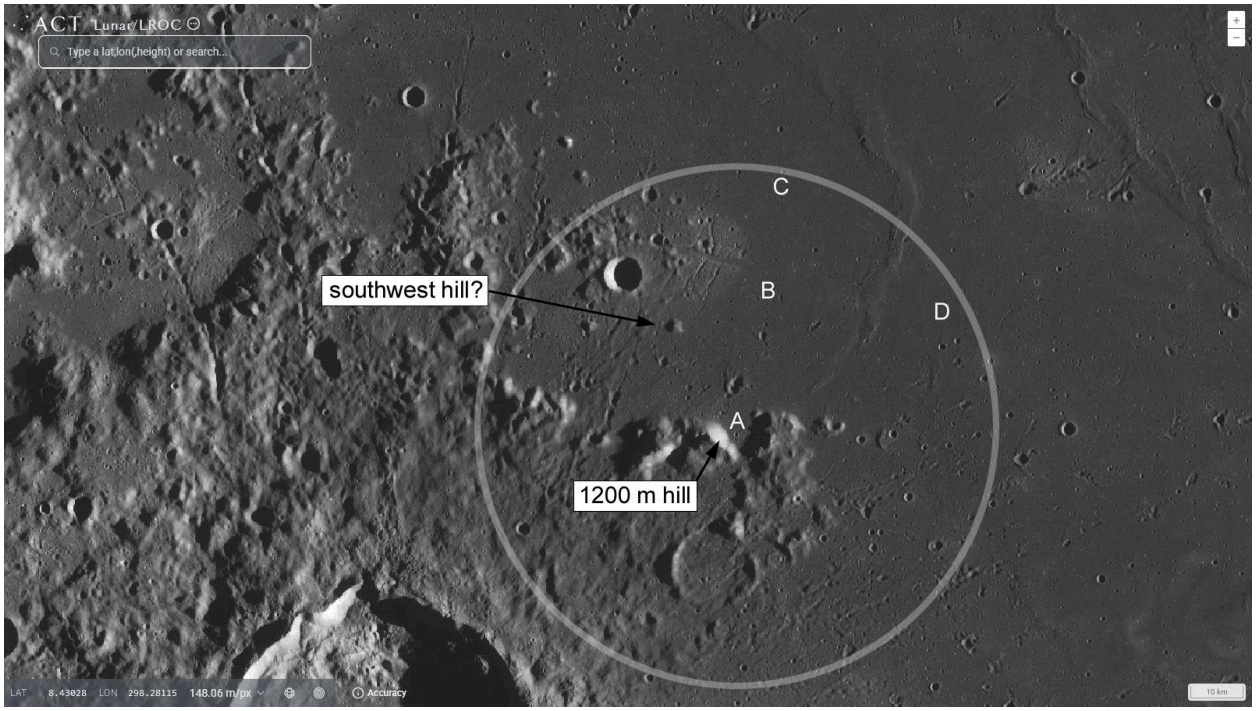


A synthetic panorama from a location 30 km north of the old Soviet site, made using Quickmap. A 'spire' in the valley to the left of the biggest hill is just a bad pixel in the topographic data.

February 4, 2025 - #moon #luna9

This map shows the Luna 9 area (from Quickmap again). A is the usual site. B was my older estimate, putting a hill in the right place to be SW hill. C is far enough north to lose the big hills but then where is SW hill? But over at D, still inside the Soviet 50 km radius circle, the 1200 m hill could actually be the SW hill - all its neighbours are now below the horizon.

Is this correct? We can't prove it unless we can find Luna 9 in LRO images. We will consider that tomorrow.



An LRO wide angle mosaic of the Luna 9 area, from Quickmap, is overlaid with a 50 km radius circle and several points examined to see of they might be the Luna 9 landing site. Somewhere northwest of the middle of the circle seems to give a better estimate.

February 5, 2025 - #moon #luna9

Want to find Luna 9? You are not alone, but many people have looked for it without success. All the points I have made about uncertainty in the location help to explain why. We don't know where to look. But feel free to scroll through hundreds of full LRO Narrow Angle Camera images (each one 5000 by 50000 pixels) looking for something very small.

What are we looking for? This link goes to a mission description with an image of the landing process:

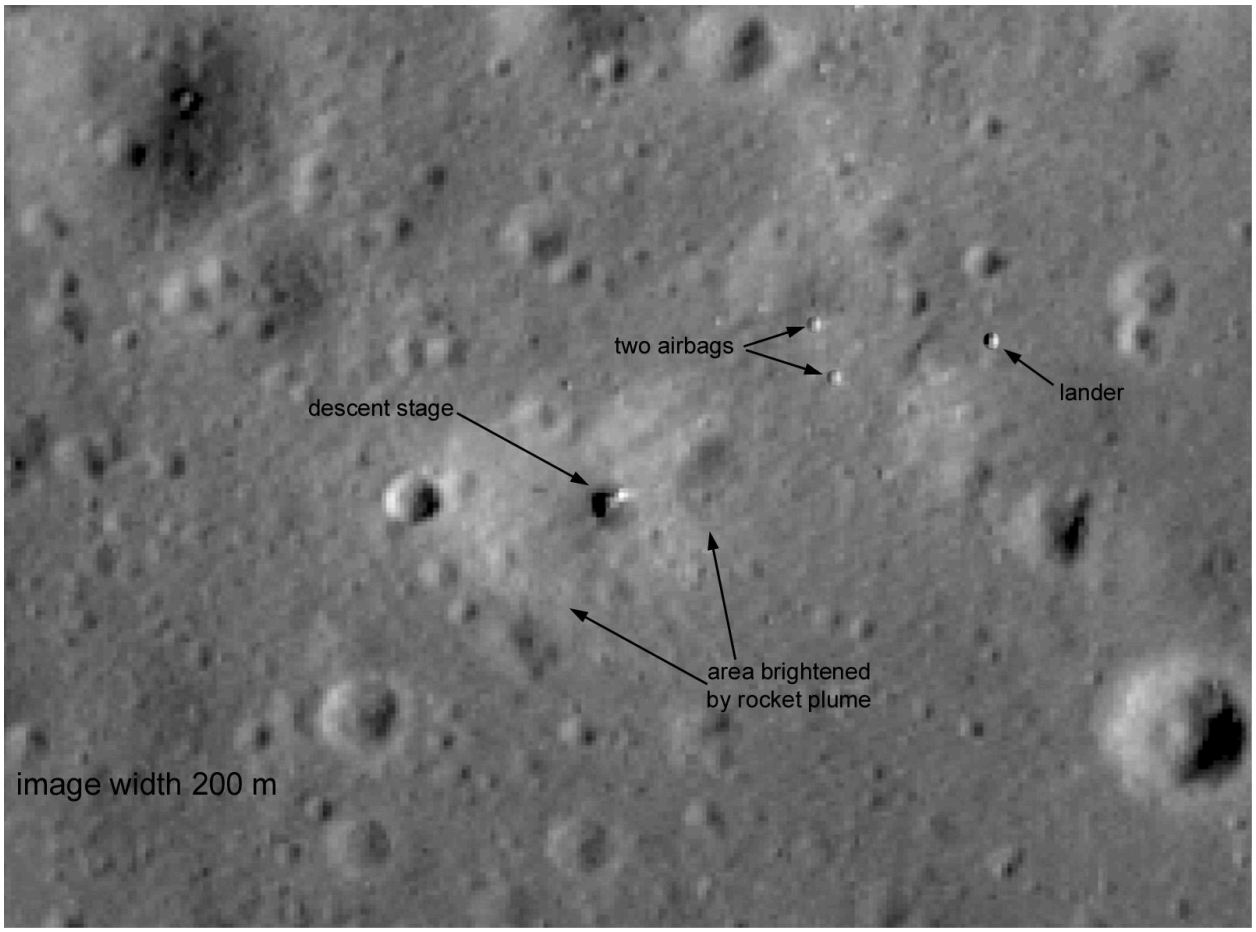
https://www.russianspaceweb.com/luna9.html

February 5, 2025 - #moon #luna9

(Russianspaceweb is a fantastic resource). The lander is 30 cm across (bigger with its petals) but it's barely resolved and will look like a rock. But there's more to look for. We start with the main spacecraft reaching the ground and shutting down its thrusters (far right). It ejects its landing capsule, encased in a protective 2-lobe airbag. The airbag splits and falls aside, the lander rolls to a stop and opens its petals, thereby righting itself.

February 5, 2025 - #moon #luna9

Here is a view of what it might look like. This is Luna 23 with some fictitious added details. The decent thrusters brighten the surface (we see this at most sites) so we can look for that and the main spacecraft itself. It dropped 2 equipment pods earlier but probably not close by. Then we might see the airbag sections and the lander itself. The lander will just look like a rock but the ensemble will be the evidence we need. But there's more to look for as well...



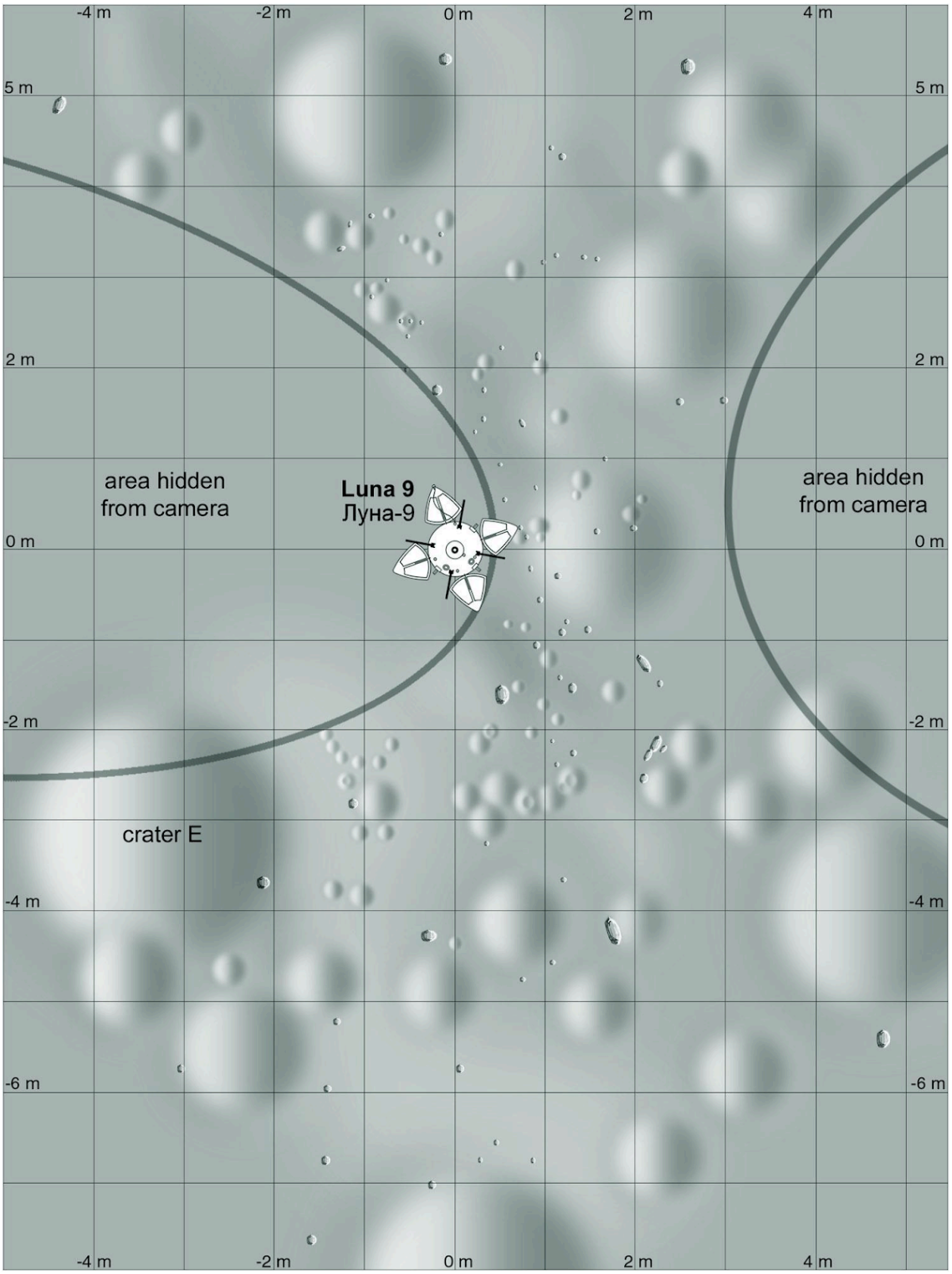
A suggestion for the appearance of Luna 9 on the lunar surface in an LRO image. This is actually Luna 23 and I have added two airbag sections and the landing capsule to match the Luna 9 hardware. The lander is probably surrounded by a bright spot about 30 or 40 m across made by the landing rocket plumes.

February 6, 2025 - #moon #luna9

Because Luna 9 took pictures we have maps of the surroundings. So we can look for the pattern of craters around Luna 9 as well as the hardware. Between the two we should get a solid identification... IF we can find it.

Let's look at maps of the site. The Soviet publication 'First panoramas of the lunar surface' (Moscow: Akademiya Nauk, 1966) included maps drawn from the images. My map here is a shaded relief version of their drawn maps.

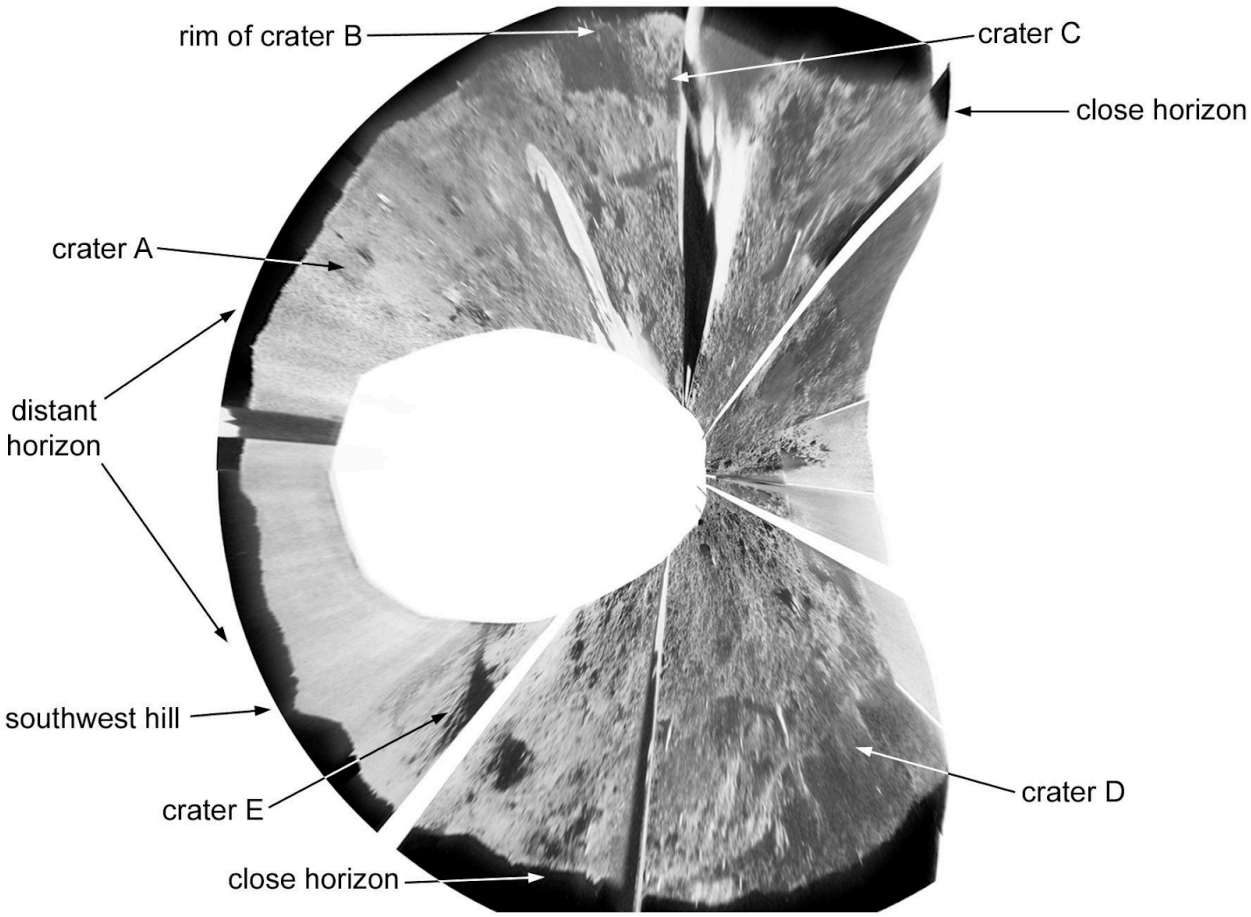
(Image on next page)



A map of the area around Luna 9 showing the lander, craters and rocks. Two arcs show regions out of view of the camera. The map is a shaded relief representation of two drawn maps in a Soviet-era book about the mission.

February 6, 2025 - #moon #luna9

That sounds easy ... but the map is only an interpretation of rather small low angle images. Rolling terrain, lack of stereo at a distance and low resolution make mapping difficult, especially the more distant features. How far away is the northern horizon? We can't really tell. Here is a version of the panorama projected into a circle (my party trick) - it's not easy to relate the previous map to this image. If we find this place in LRO images we should be able to match features.



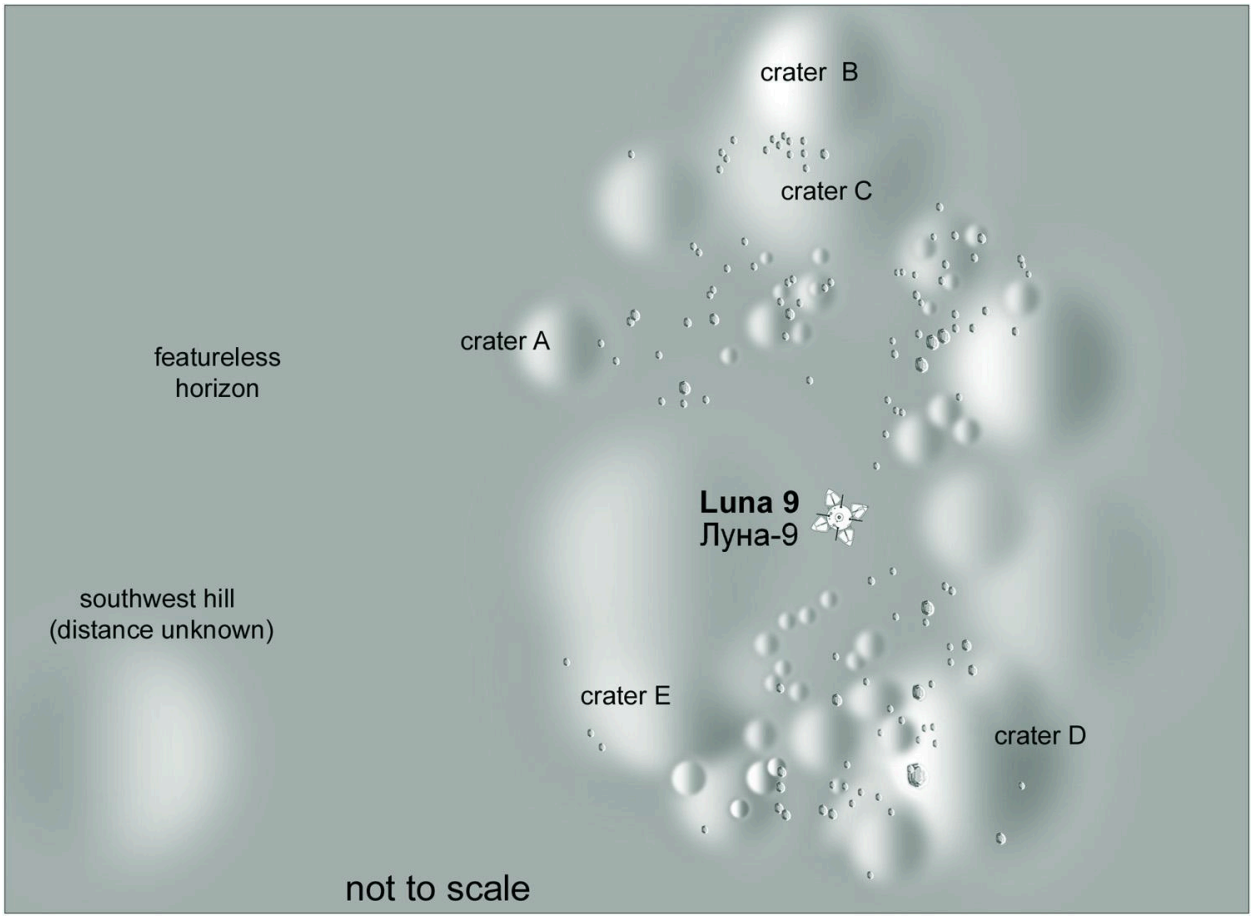
The Luna 9 panorama projected into a circle with north at the top. The larger of these features should be seen in LRO images if we can find the site.

February 6, 2025 - #moon #luna9

To complicate matters further, here is a map drawn basically just using the projected panorama. It doesn''t match the earlier map very well so which should we use?

These are difficult problems but one day a human being will solve them. Are there other approaches? Hyperspectral or radar imaging capable of detecting metal fragments? Maybe, but not at resolutions available to us today.

That's enough about Luna 9. Time to move on to some orbiters.



A map of the Luna 9 area drawn using the projected panorama.

February 7, 2025 - #moon #luna10

Luna 9 was followed by the orbiters Luna 10, Luna 11 and Luna 12. Luna 10 was the first spacecraft to orbit any body beyond Earth. Luna 11 was intended to take pictures of the surface (again on a film camera) but it failed (its orientation could not be controlled). The descriptions of the missions at NSSDCA fill in the details:

Luna 10:
https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1966-027A

Luna 11:
https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1966-078A

They returned data on radiation, lunar gravity and composition. Tomorrow: Luna 12.

February 8, 2025 - #moon #luna12

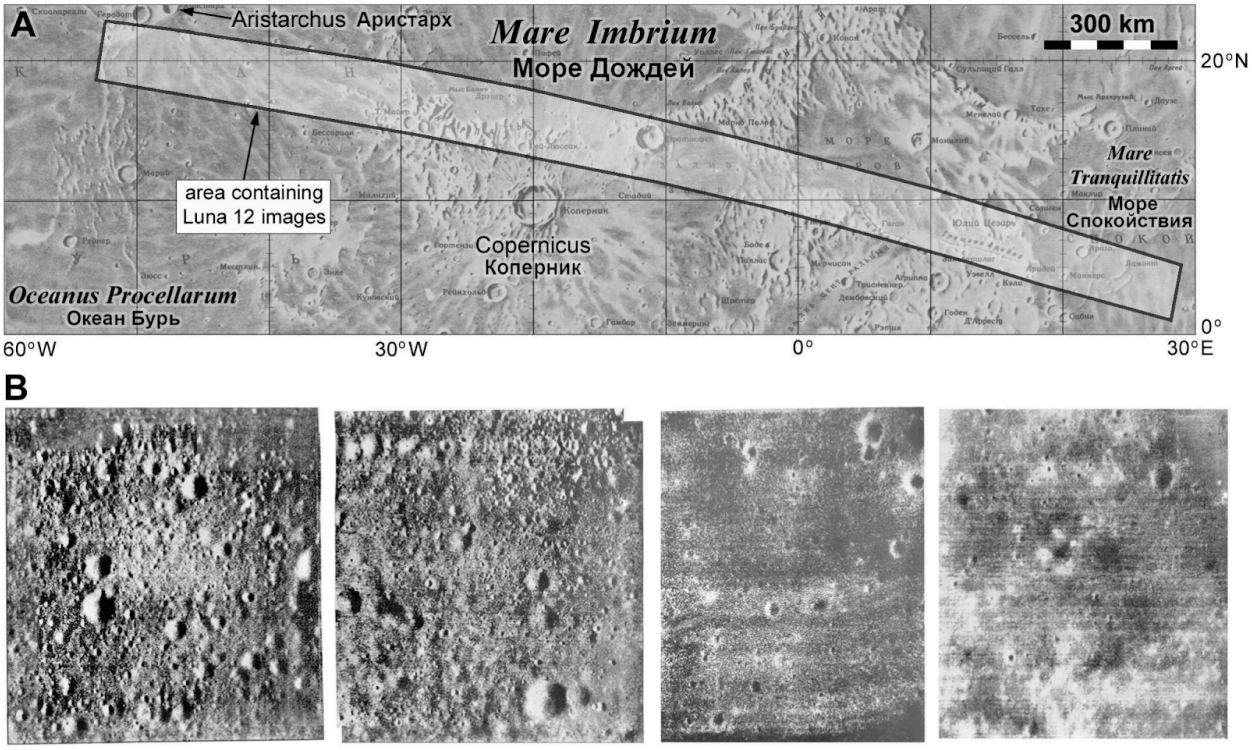
I didn't go into much detail with Lunas 10 and 11 because my main interest is in missions which produce images or whose locations or rresults can be mapped. Luna 12 allows both. The basic details of the mission are given here:

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1966-094A

It says only 2 images were released but we actually have 4:

http://mentallandscape.com/C_CatalogMoon.htm

Here are the images and a map of the area in which they were taken (from a Soviet popular space book whose details I have lost).



Four images taken by Luna 12 and a map of the general area covered by Luna 12 pictures - a swath running from near Aristarchus to Mare Tranquillitatis).

February 8, 2025 - #moon #luna12

About 40 images were taken, but this is all we have. I should point out that the Soviet Union never undertook systematic mapping of any world except Venus (Venera 15 and 16 radar mappers).

Each image is about 5 km across and the resolution is 5 m/pixel. This is just about adequate to plan human landing missions, but many more images would be needed, and closer to the equator. The Soviets never took the pictures needed for human landings, and yet they did select landing sites.

February 8, 2025 - #moon #luna12

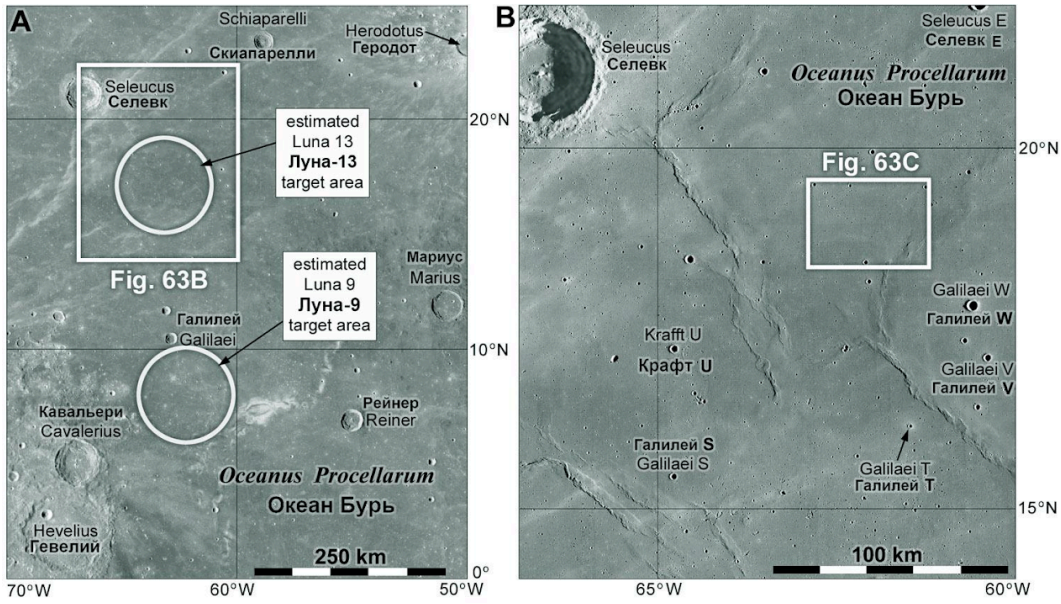
The two images at left are said to be near Aristarchus (27 October) and the two at right are in Mare Imbrium (29 October, despite the NSSDCA details about pictures). The exact locations have not been found.

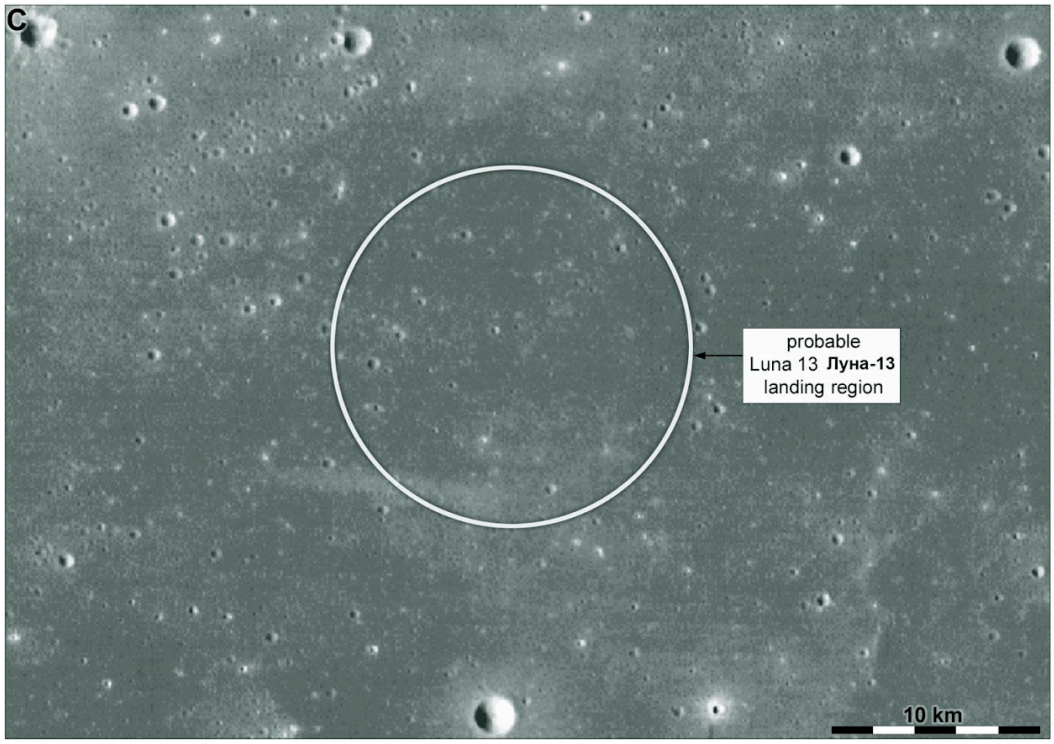
So how were cosmonaut landing sites chosen? I will look at it later, but let's say they had to be using NASA's Lunar Orbiter images, or conceivably the maps and photomosaics prepared from them by the US Army and Air Force, but we don't know the details.

February 9, 2025 - #maps #moon #luna13

Moving on to Luna 13, again we don't have an exact location. Map A shows the region with the Luna 9 and 13 probable target areas (ray-free maria). Map B closes in on the landing site and Map C is a closer view. I must emphasize I have never seen an estimate of uncertainty and the stated coordinates (NSSDCA: 18.87 N, 62.05 W) are far too precise (they are just the centre of the landing area). The landing could be anywhere in Map C, and my circle is not an error ellipse.

(Image on next page)





Maps of the Luna 13 landing site. At top left is the landing region in western Oceanus Procellarum. The estimated targets of Luna 9 and Luna 13 are shown, in ray-free basalt plains. At top right the landing area is shown in more detail. At bottom a map zooms in on the expected landing area, but we do not know the exact site and it could be anywhere in this map. A circular outline is centred on the stated coordinates but it is not an error ellipse and is certainly smaller than the true uncertainty.

February 11, 2025 - #moon #luna13

Back to Luna 13, here is the NSSDCA page about the mission:

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1966-116A

The picture shows a spacecraft similar to Luna 9, except it has 2 cameras on top instead of 1 and two folding arms which deployed instruments to the surface to measure its hardness and density.

Here, on Don Mitchell's site:

http://mentallandscape.com/C_CatalogMoon.htm

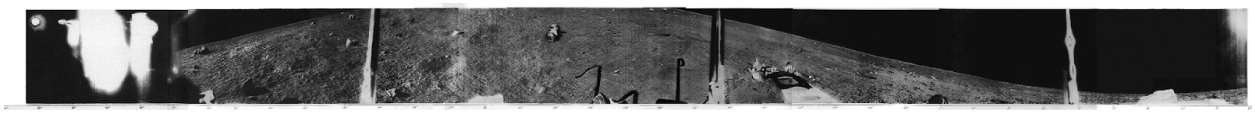
about 1/4 of the way down the page, are the 5 panoramas taken by one of the cameras. The other didn't work.

February 11, 2025 - #moon #luna13

The first panorama is only a fragment but the others are more complete. They can be joined to create a full panorama, and you will see the spacecraft shadow changing as the Sun gets higher in the sky. Someone could animate that. There are a few fragments of hardware, presumably from the fallen descent stage - the lander popped off it as it touched down and rolled some distance away. Tomorrow, my version of the full panorama. #moon #Luna13

February 12, 2025 - #moon #luna13

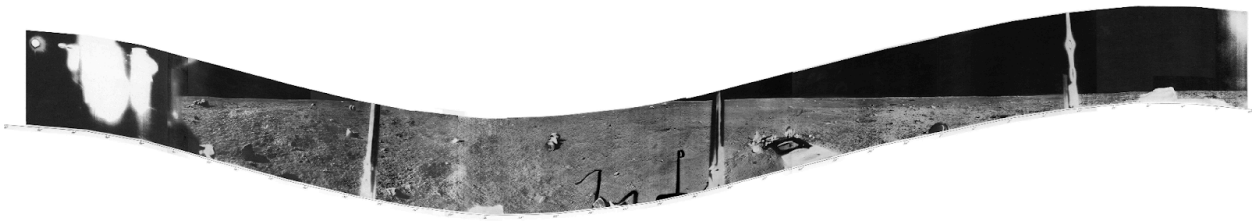
Here is the full Luna 13 panorama, made by joining sections of the 5 panoramas to fill gaps. No dihedral mirrors this time, but the 4 antennae are the same as Luna 9, except that we only see 3. One is hidden by a fuzzy blob at the left edge. There were 2 cameras and the blob is the second camera seen very close up by the first. The second camera didn't work. The middle of the view faces a bit south of west. #moon #Luna13



The Luna 13 panorama, made by joining sections of 5 panoramas to fill gaps. A smooth surface runs out to a nearly featureless horizon. There are a few rocks and scattered fragments of the descent rocket stage.

February 12, 2025 - #moon #luna13

And here is a version with the horizon rectified. It's almost flat, exactly as we would expect for a site far from any large hills or crater rims. The shadows of lander antennae are seen near the middle and one of the arms with a densitometer (measuring the density of the regolith) is to its right. #moon #Luna13



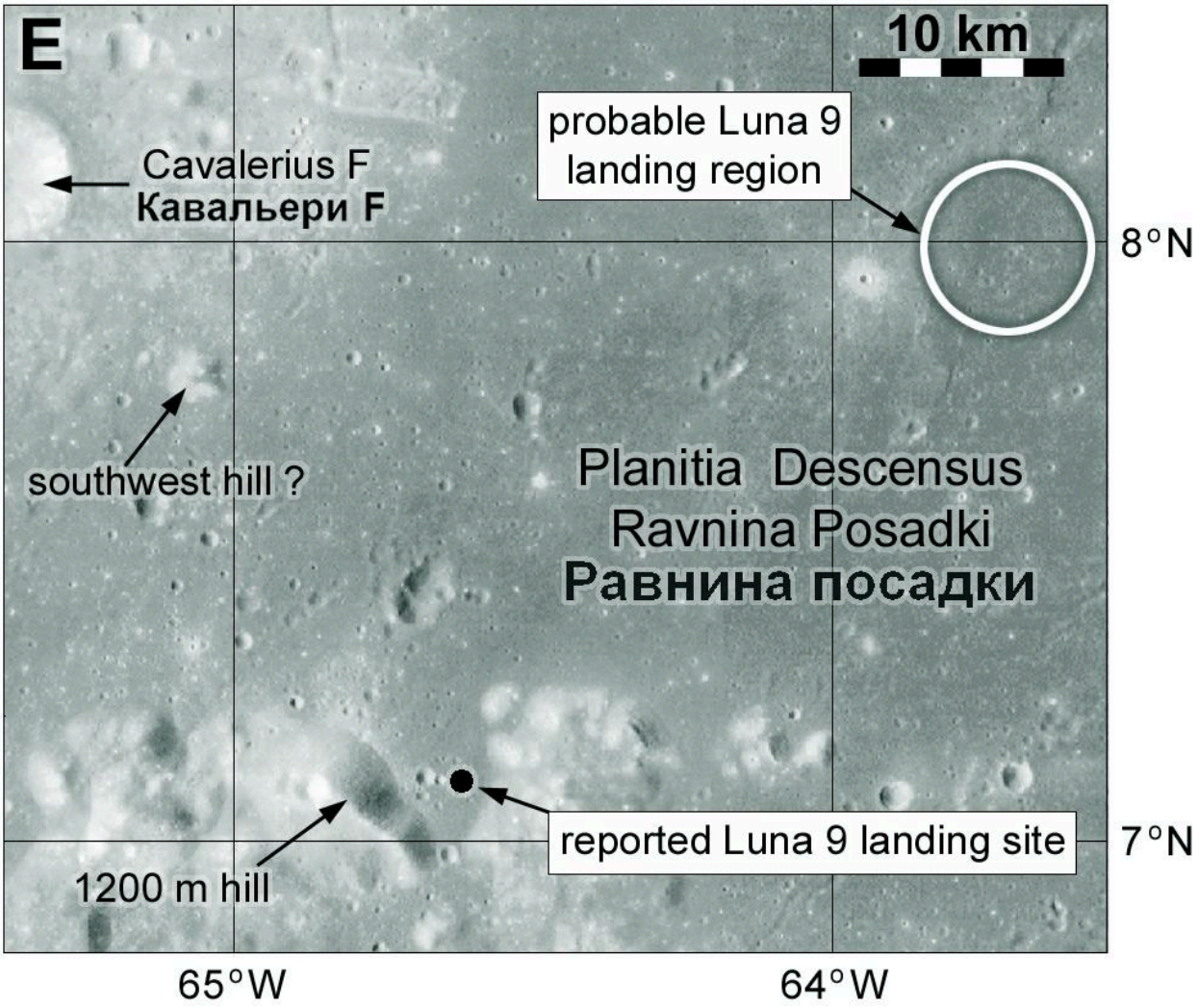
The Luna 13 panorama rectified to make the horizon level. It's almost completely flat.

February 13, 2025 - #moon #luna9

I'm going to step back in time slightly to look at the Luna 9 location again, then do the same for Luna 13. I'm working on the Luna 9 problem at the same time I'm posting this sequence. I said we don't know how far away the 'southwest hill' is, but still talked about possibly seeing it in the panorama. I now prefer to discount it (i.e. it's a small local mound, not a distant mountain). It looks like you have to go too far north to avoid seeing the 1200 m hill and other mountains.

February 13, 2025 - #moon #luna9

The Luna 9 panorama does have a bit of local relief on the horizon, especially to the north (see the circular projection of the panorama, though note its horizon relief is exaggerated in that view). I'm moving my preferred location east, just east of a wrinkle ridge in the plains. That ridge will give us a bit of irregularity on the horizon, and might just raise the level of the local horizon enough to hide the distant hills. Here's my new guess.

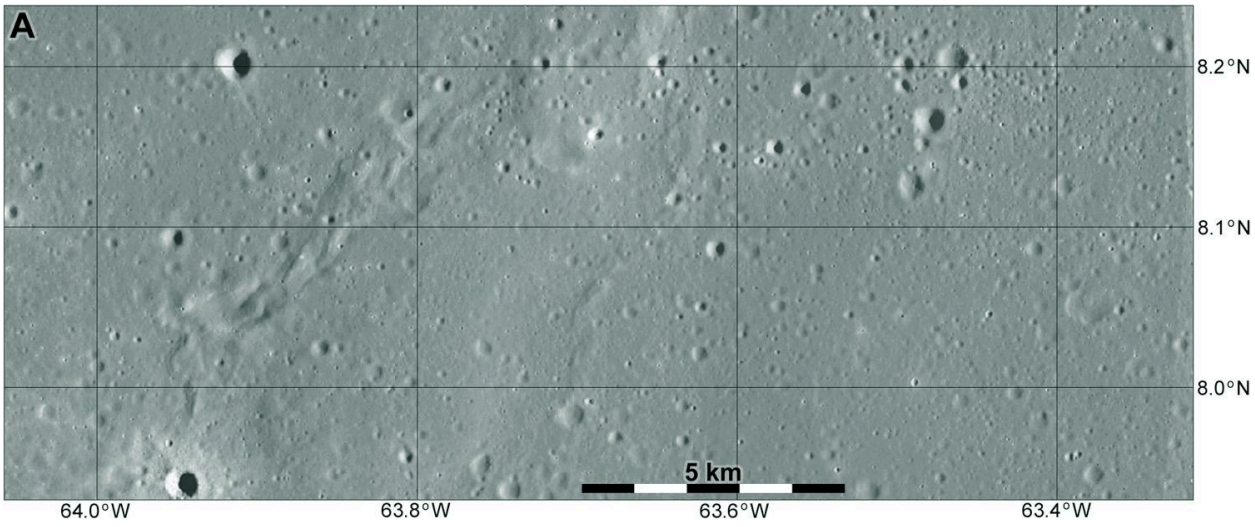


A modified version of a map I posted a week ago showing the Luna 9 landing area. I have moved the site I now prefer to the east, where a local ridge puts a bit of relief on the horizon to the north and maybe allows the ridge to conceal the high hills to the southwest.

February 13, 2025 - #moon #luna9

That puts the landing somewhere in this map. Obviously we can't prove anything here, and I hope this illustrates just how hard it is to figure out where to look for the lander in LRO images.

OK, now we will come back to Luna 13 and see what constraints there are to its location. It's not many! There is a great discovery waiting for someone in images which are already on the ground.

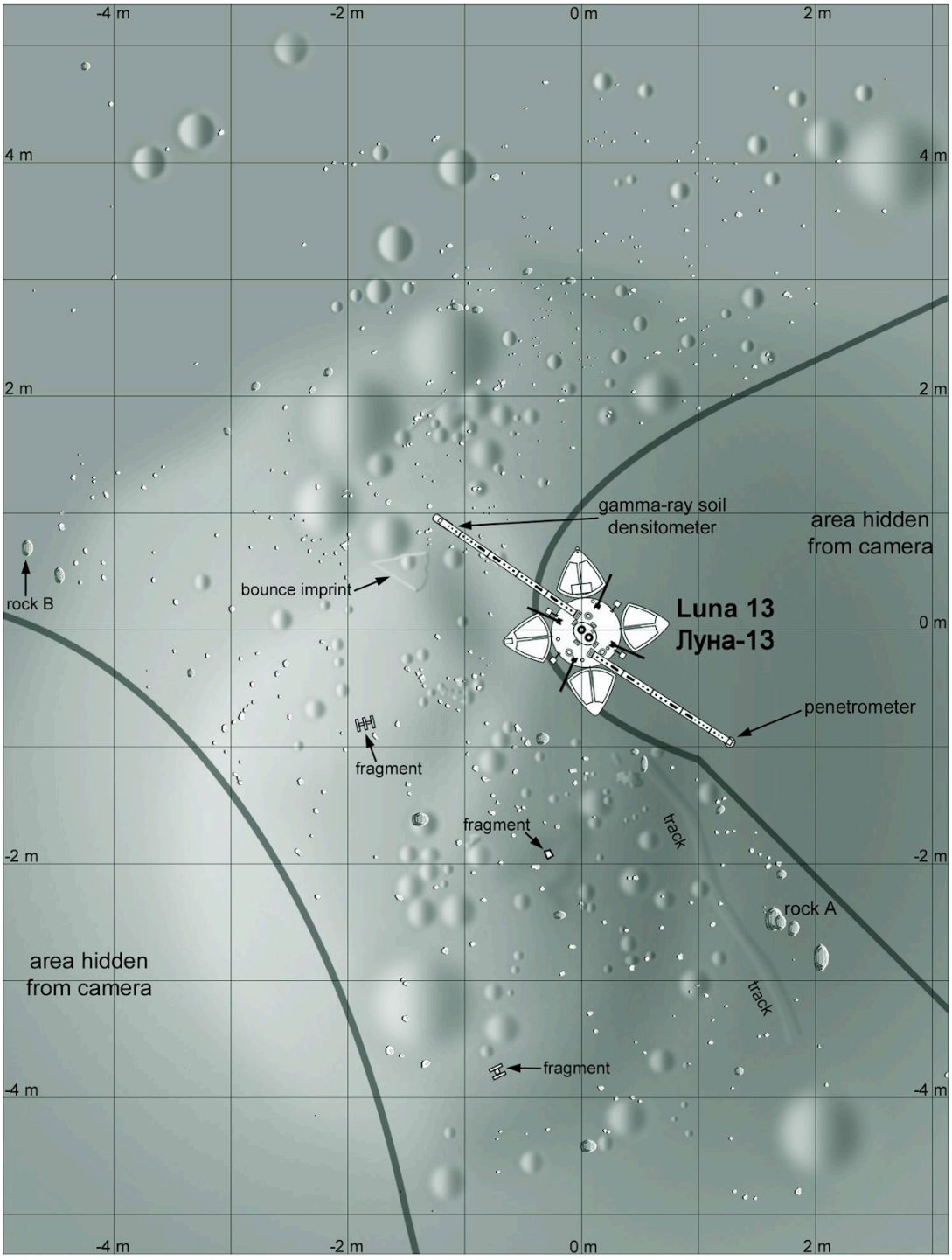


A closeup of the area now favoured (by me) for the location of Luna 9. The ridges visible in the left and central parts of this image may hide the hills to the southwest.

February 14, 2025 - #moon #Luna13

Back to Luna 13, and it's time to consider how we might find it. The pattern of artifacts will be similar to what I showed for Luna 9, a schematic image showing a bright patch around the descent stage, the lander only about 1 pixel across, and maybe the two airbag fragments. Also we can look for the pattern of surface features seen in the panorama. Here is a map of the landing site, a shaded relief rendition of a drawn map in the soviet source (ref in next post).

(Image on next page)



A shaded relief map of the Luna 13 site based on features seen in the panoramas. The lander is added with its two extended folding arms, which placed instruments on the surface. It seems to have landed in a subdued crater.

February 14, 2025 - #moon #Luna13

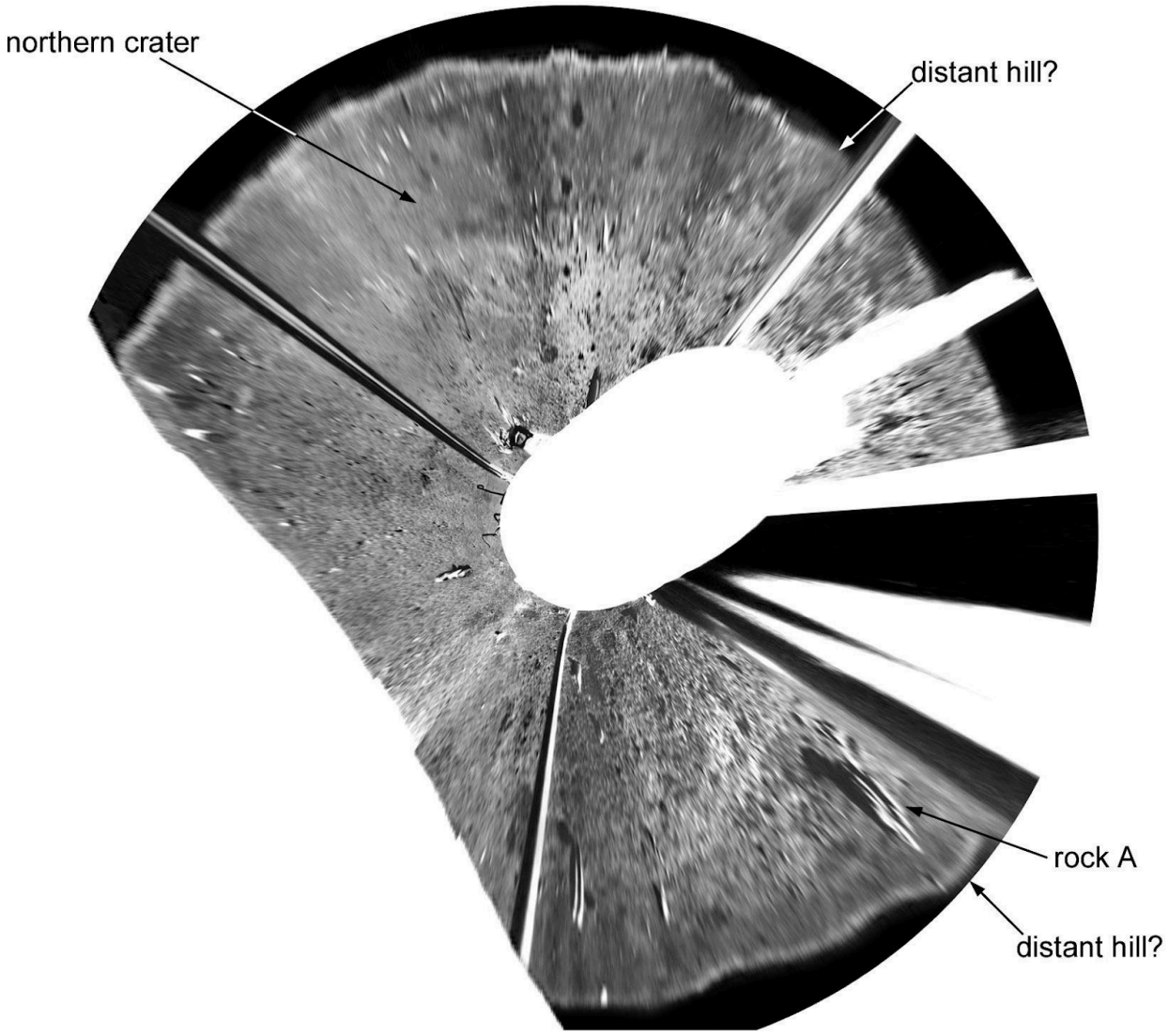
The source of the map is:

Academy of Sciences of the USSR, 1969. First panoramas of the lunar surface, Volume 2. Moscow: Akademiya Nauk.

It's not always easy to locate these features in the panorama reliably. Looking at the pictures, I feel that the big 'rock A' feature might be bigger and further from the lander than this suggests. The lander would be only 1 or 2 LRO NAC pixels across and almost everything in this map is smaller. What lies further away, towards the horizon?

February 15, 2025 - #moon #Luna13

This is a version of the Luna 13 panorama projected to make it easier to compare with an orbital image. The most significant feature is the 'northern crater' which is far enough away that it and he small craters inside it would be big enough to see in orbital images. I think that offers the best chance of finding Luna 13. We should see that crater and the pattern of features expected for the lander and its other hardware. I have looked, but no luck yet.



The Luna 13 panorama projected into a circular view for comparison with orbital images. A crater lies north of the lander and it plus the smaller features inside it should be visible on orbiter images if we can find the right place.

February 15, 2025 - #moon #Luna13

This is a rough sketch map showing those distant features. It's hard to be sure of the size of that crater. There is a hint of similar features to the southeast in the projected panorama but I did not try to map them. I think Luna 13 should be easier to find than Luna 9 based on this approach. I have idly speculated that 'rock A' might even be the fallen descent stage, but that is probably not true.

February 15, 2025 - #moon #Luna14

After Luna 13 we have to wait a while for another surface mission. I won't go into much detail where we don't get pictures. Kosmos 159 was supposedly similar to Luna 12 but was operated only in a highly elliptical Earth orbit. It's not clear if it was intended to go to the Moon. Luna 14 did orbit the Moon, testing communications and measuring radiation, gravity and lunar surface radar reflectivity.

February 16, 2025 - #moon #Zond

Now we move to a new class of lunar spacecraft, Zond. But this is nothing like Zond 3, the old Mars probe which was repurposed to image the far side of the Moon. These Zonds were what later became Soyuz spacecraft, initially designed to carry people to the Moon and later to Soviet space stations. And the timing is significant - this is the second half of 1968, with Apollo ramping up and not much time for a Soviet mission to leap ahead. Tomorrow we will get to grips with the Zonds.

February 17, 2025 - #moon #Zond

The purpose of the spacecraft series we call Zond 4 to Zond 8 was to perfect a very complex trajectory and re-entry before humans were entrusted to them. Later they became the Soyuz spacecraft still used for space station crews. I don't know what they would have been called if they took people to the Moon. The first was called Zond 4, early in 1968. It was sent to lunar distance but 180 degrees from the Moon so lunar gravity would not complicate its orbit. On return...

February 17, 2025 - #moon #Zond

... on return Zond 4's guidance system failed and it hit the atmosphere without performing its 'skip' out of the atmosphere and back in at lower velocity. The spacecraft was destroyed over the Atlantic Ocean near Africa so it would not be recovered by the US.

Next, in September 1968, was Zond 5. This flew around the Moon and back to Earth with a biological payload (turtles and various invertebrates, plants etc. But again its return was compromised.

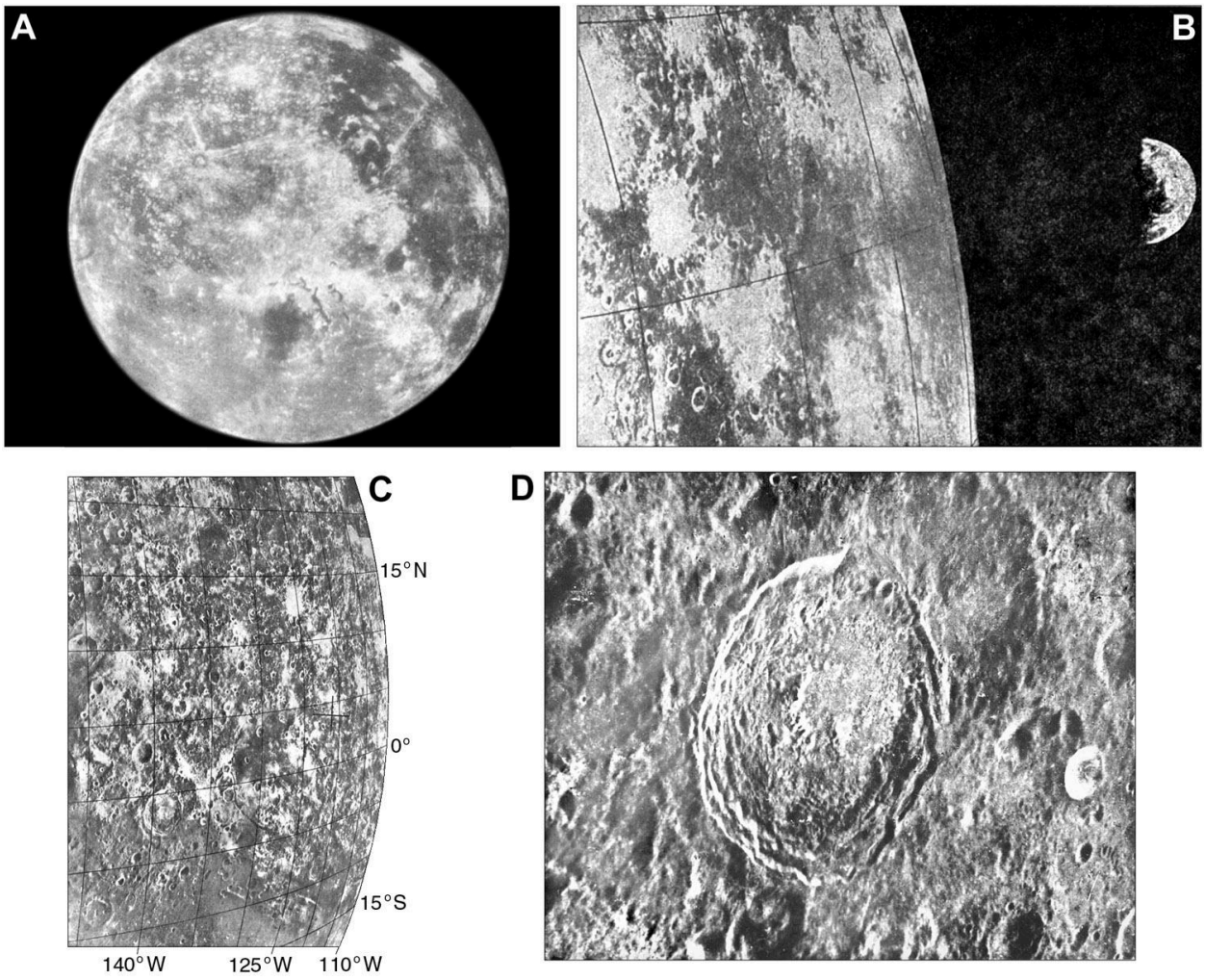
February 17, 2025 - #moon #Zond

Zond 5 lost attitude sensors, could not land in the Soviet Union but fell into the Indian Ocean where it was recovered. Cosmonauts might not have survived the re-entry. Images of Earth were taken but not the Moon (at least none were released).

Zond 6 flew a better trajectory and this time brought back images of the Moon. The landing was again spoiled (parachutes ejected at high altitude). This and other problems would have killed a crew. This was only a few weeks before Apollo 8.

February 17, 2025 - #moon #Zond

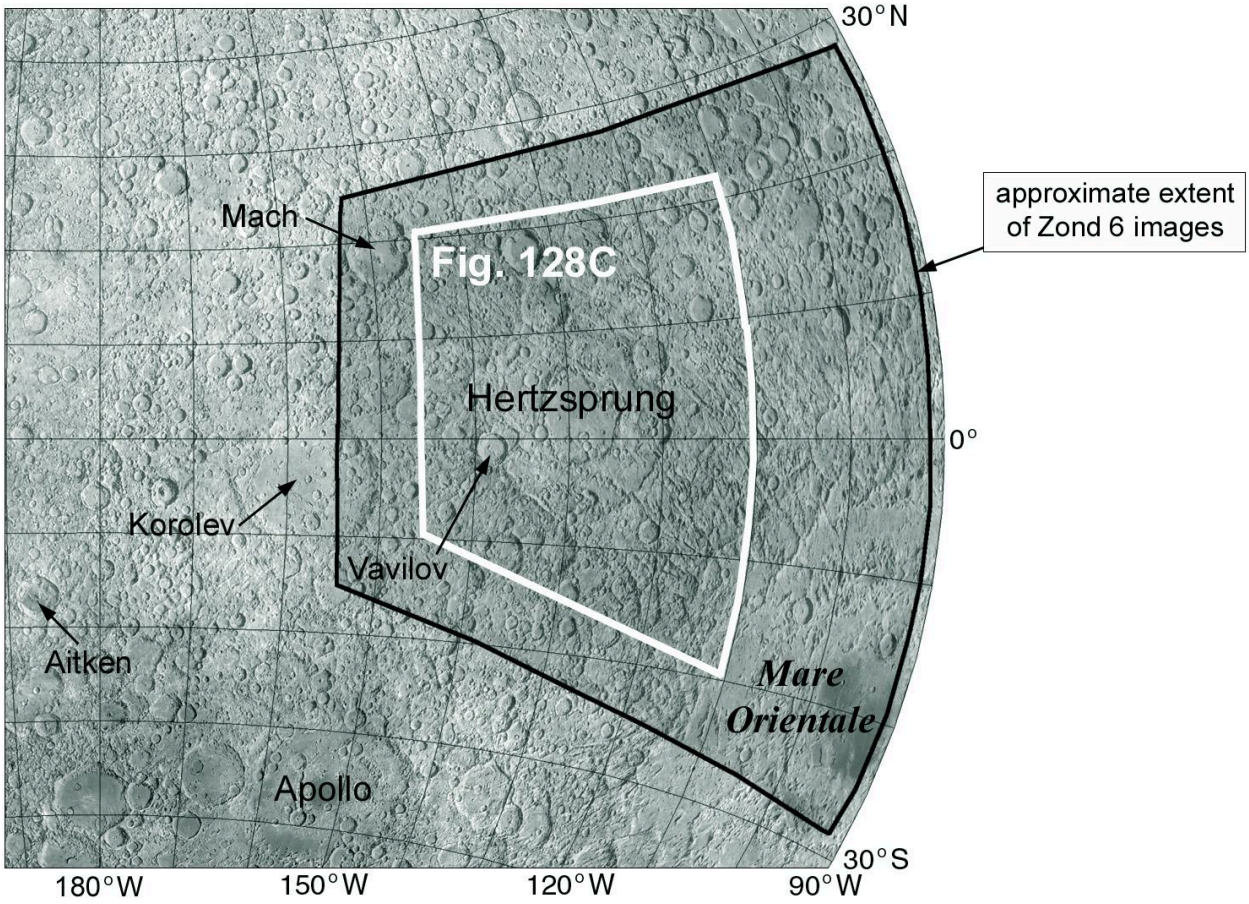
Zond 6 images taken on film were nearly lost when the spacecraft crashed in Soviet territory. The film container was split and light spoiled some pictures, but enough were intact that some scenes could be recovered. Here (from material I scanned in Moscow) are views of a full-phase disk centred north of Orientale, A limb view with Earth, a mosaic of frames covring part of the farside, and a close-up of Vavilov crater.



Zond 6 images of (top left) a full phase view of the Moon centred north of Orientale, a view (top right) of Earth over the lunar horizon, a mosaic of images on the farside (bottom left) and a closeup of a crater called Vavolov (bottom right).

February 17, 2025 - #moon #Zond

This map is based on a Zond 6 image index map I scanned at MIIGAiK. The region covered here was mostly seen by Lunar Orbiter obliquely near the terminator, and the Vavilov image shows some Zond 6 coverage was the best available at the time. The most significant science was from the full disk view. Careful measurement of the limb at lower left revealed a huge depressed area - the South Pole-Aitken basin (ref in ALT text).



A map of image coverage of Zond 6 based on an index map seen at MIIGAiK in Moscow. The image coverage was mostly on the farside near the equator. The full disk view in the previous post had its limb running down the central farside and measurements revealed a huge depression south of the equator. This was the first evidence of what is now called the South Pole-Aitken basin. Here is the reference:

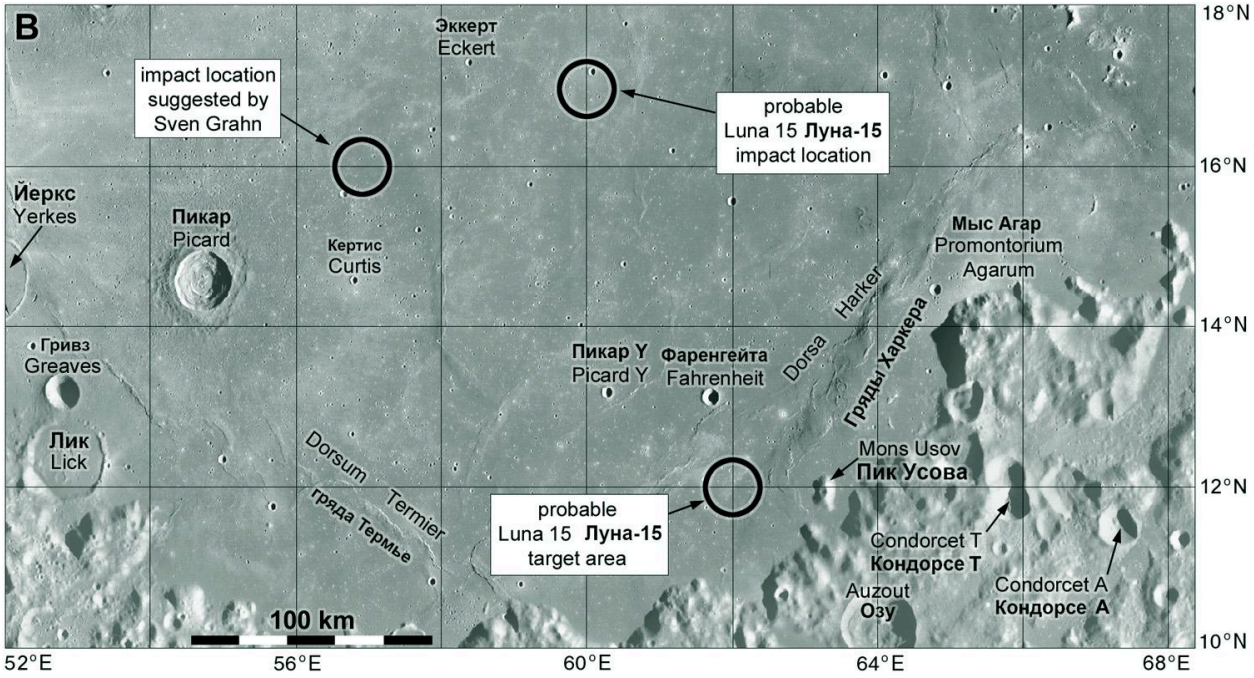
Rodionov, B. N., Isavnina, I. V., Avdeev, Yu. F., et al., 1971. New data on the Moon's figure and relief based on results from the reduction of Zond 6 photographs. Cosmic Research, v. 9, no. 3, pp. 410-417.

February 18, 2025 - #moon #Zond

Next up after Zond 6 was Luna 15, a sample return lander which flew at the same time as Apollo 11. This was a last-ditch effort to bring a sample back before Apollo, allowing the Soviet Union some small bragging rights. If Luna 15 had followed the flight profile of Luna 16 it might have returned lunar samples slightly ahead of Apollo 11, but it spent an extra day in lunar orbit and lost that chance. Then it crashed the day after Apollo 11 landed - but where?

February 18, 2025 - #moon #Luna15

This map shows some sites. NSSDCA says 'the spacecraft impacted the lunar surface on July 21, 1969 ... at an estimated position of 17 N, 60 E. Other references give the crash site as 12 N, 59 E or 17 N, 49 E.' It's our old familiar story - we have not one possible site but several (there are other suggestions too). What's a poor cartographer to do? I hope that one day we will have better documentation for this from dusty file boxes in the Lenin Library.



A map of Mare Crisium showing the site of the Luna 15 crash site. Or rather, two possible sites, and others could have been added. As with so many early Luna missions, we simple don't know where it really is.

February 19, 2025 - #moon

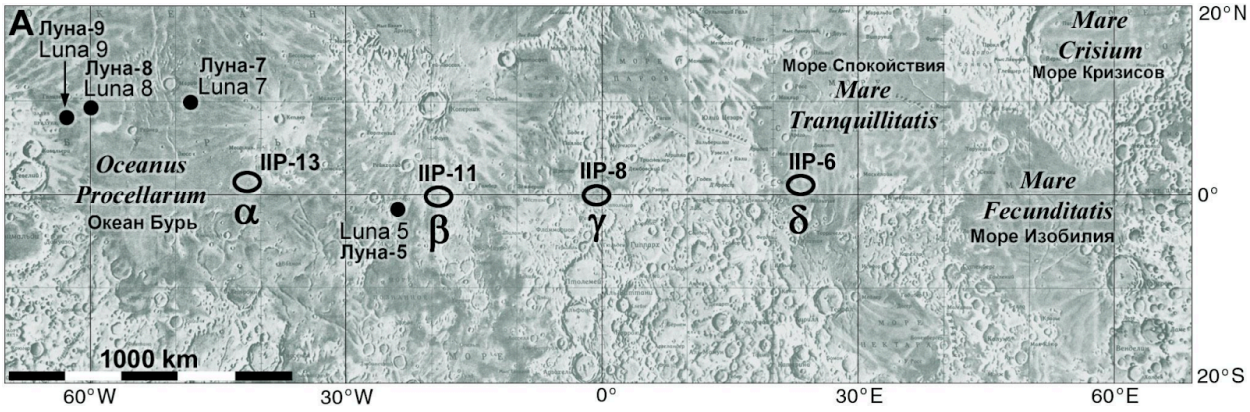
The next Soviet mission would be Zond 7, but also around this time in 1968 people were working on landing site selection for Soviet cosmonauts. The chance to be first was gone, but while a landing was still being considered sites were needed. I said earlier that Soviet missions never undertook systematic mapping or took images good enough for site planning with the dubious exception of Luna 12 (just barely adequate but very few images and too far north).

February 19, 2025 - #moon

It follow that any serious work was done using NASA images - Lunar Orbiter images - and therefore sites were limited to Lunar Orbiter targets used for Apollo planning. 3 equatorial regions in the western, central and eastern maria were studied, just as for Apollo. These were in Oceanus Procellarum, Sinus Medii and Mare Tranquillitatis. Basilevsky told me that Sinus Medii was rejected (too rough) leaving just the eastern and western areas in consideration.

February 19, 2025 - #moon

Basilevsky spoke at the Brown-Vernadsky Microsymposium in The Woodlands, Texas on 16 March 2014. He showed 4 sites corresponding to sites IIP-6, IIP-8, IIP-11 and IIP-13 as the potential landing areas. In 2016, 2017 and 2018 he taught a short course in Planetary Geology at the Macau University of Science and Technology, and a presentation from that class showed these sites labelled alpha, beta, gamma and delta (from west to east). Gamma was rejected.



A map of the equatorial nearside of the Moon showing four sites studied by Soviet scientists to choose a landing site for cosmonauts. The landings never happened. The sites are near the equator and they correspond to potential Apollo sites images by Lunar Orbiter because the Soviets never took their own images good enough for site selection. How did they get the images? The story has never been told.

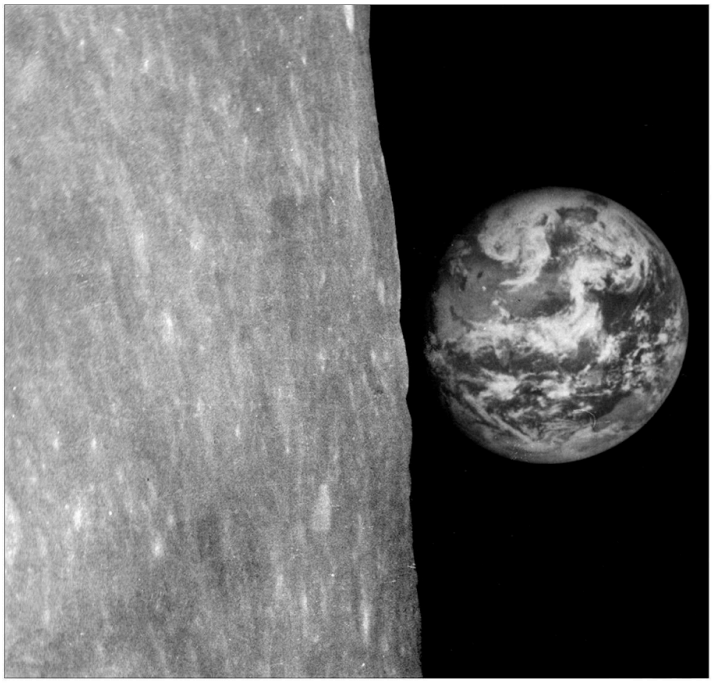
February 19, 2025 - #moon

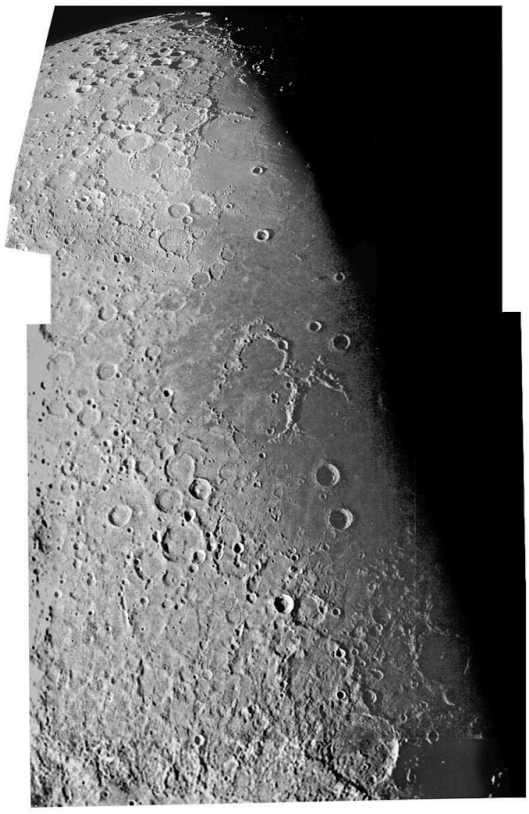
The one thing we don't know is if specific points or ellipses in those rather large Lunar Orbiter 'sites' were chosen. The word 'site' can be misleading. Delta is the Apollo site IIP-6 or Apollo site 2, used for Apollo 11, but any Soviet landing would not be in the specific Apollo 11 ellipse.

How did the Soviets get the images? We don't know. I've seen Jim Head teasing Basilevsky about it at a conference but Sasha couldn't say.

February 20, 2025 - #moon #Zond

Zond 7 was the next test flight of the spacecraft intended to fly people to the Moon. It was a very successful flight and the only one which would have landed a crew safely, if it had a crew. But it didn't - it flew some turtles and a radiation sensor package, and it took pictures of Earth and the Moon. Here are two images from the mission, Earth over the limb (Earth is setting, not rising) and a mosaic of image running down the terminator showing Oceanus Procellarum at right.



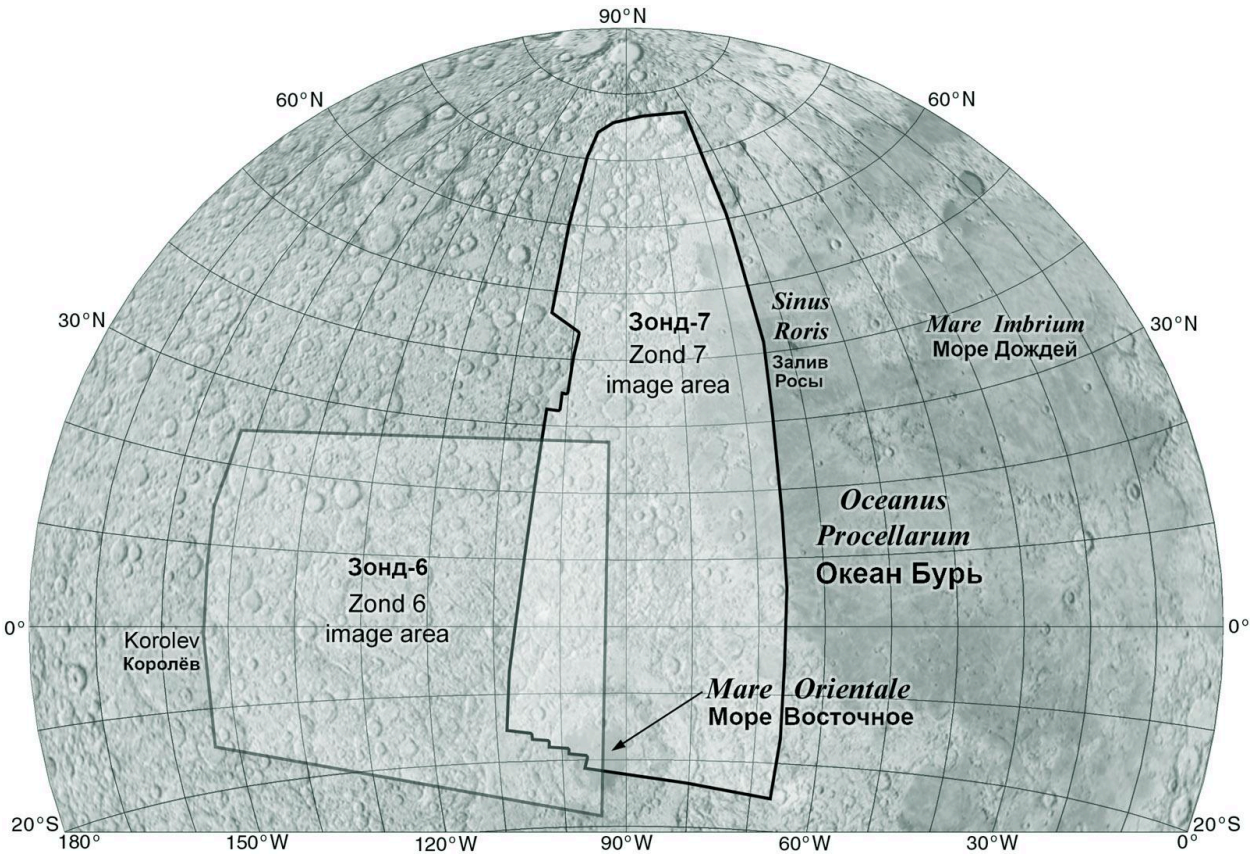


Two pictures from Zond 7 shot on film as the spacecraft looped around he MOon in August 1969. One shows Earth just above the lunar horizon (limb) just before it sets. The other is a mosaic of all frames I have seen. It runs down the terminator from near the north pole to the crater Grimaldi at bottom right.

February 20, 2025 - #moon #Zond

This map shows the extent of Zond 7 image coverage, extending a bit further south than my mosaic. This is from an index I scanned in Moscow.

NOTE: in my original posts for Zond 7 I accidentally called it Zond 6, which we have already covered. Posts have been corrected.



A map showing the areas covered by Zond 6 and 7 images. The Zond 7 images run down 90 degrees west (or 270 east if you prefer). I have not seen pictures from the southern end of the strip.

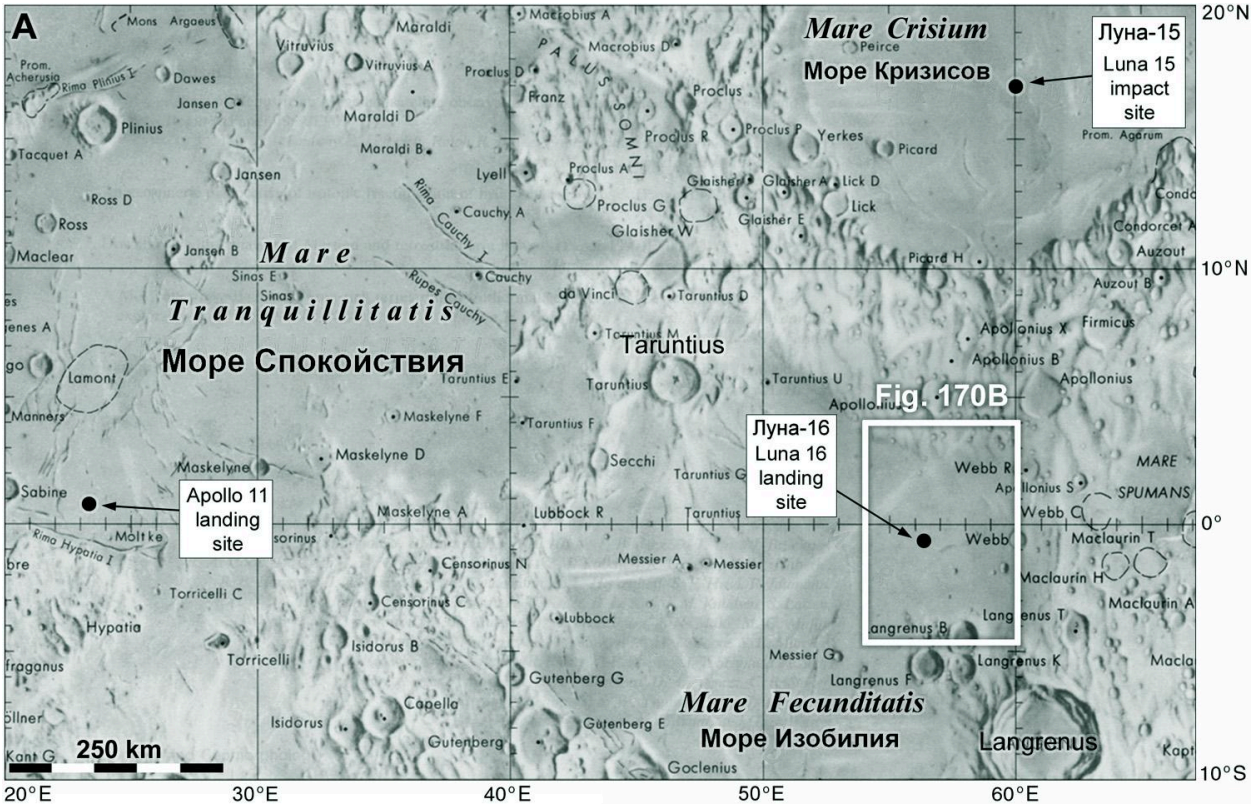
February 21, 2025 - #moon #Luna16

Luna 15 was supposed to collect lunar regolith and return it to Earth, but it crashed. The next attempt succeeded. This was Luna 16, coming in the gap between Apollos 13 and 14. The Luna sample return missions had an ingenious method of returning to Earth. To escape the Moon they had to leave it at greater than lunar escape velocity. If they do that going forwards along the Moon's orbit they are going faster than the Moon and will fly out away from Earth...

February 21, 2025 - #moon #Luna16

... but if they do it going backwards relative to the Moon's orbital motion, as they depart they are now orbiting Earth slower than the Moon, so they fall in towards Earth. By controlling the velocity and direction they can simply fall to Earth, timing it so they land in Soviet territory.

The price they paid for this convenience was a very restricted area from which to launch. All Soviet sampling missions went to a small area. This map shows the region.



A map of part of the Moon showing the landing sites of Apollo 11 and Luna 16, plus the crash site of Luna 15. Luna 16 landed safely in Mare Fecunditatis and returned a sample of lunar regolith to Earth.

February 21, 2025 - #moon #Luna16

That very restricted area was a band roughly connecting the Luna 15 and 16 sites on that map. We'll be seeing several missions go to this area. Given such a restriction, the Soviet goal was to sample Mare Crisium, Mare Fecunditatis and the strip of rugged highlands between them. Two different lava flow areas and the highlands, a good suite of samples. We'll look a bit more closely at Luna 16 tomorrow.

February 22, 2025 - #moon #Luna16

Here is a picture of Luna 16 from Wikimedia:

https://upload.wikimedia.org/wikipedia/commons/b/bb/Luna_16.jpg

My image is part of that picture, annotated. Note the two cameras.

NSSDCA describes the mission:

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1970-072A

They say: "... strong and good quality television pictures were returned by the spacecraft. However, such pictures were not made available to the U.S. by any sources ..."

The pictures were also never published in the various publications on the mission. What's going on?

(Image on next page)

Part of a picture of the Luna 16 spacecraft in its lunar sampling configuration. The picture shows an arm placing a drill on the surface, and at the top of the arm, where it is joined to the spacecraft body, two small cameras are visible, one on each side of the arm. What about their pictures?

February 22, 2025 - #moon #Luna16

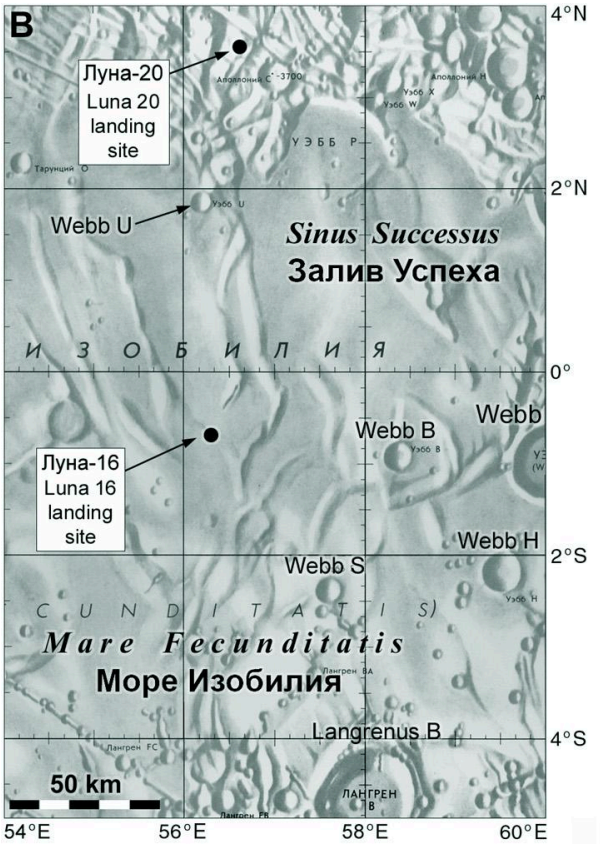
Each camera took a half-panorama from the horizon to the sampling area, so the sampling area was seen twice for stereo mapping. If a rock was in the way I think the arm could move a little to the left or right to avoid the obstacle. Why did we not see the pictures? NSSDCA points out they landed 60 hours after sunset, so not much to see! But they were taken and transmitted anyway, probably just to test the system. But what about Earthshine?

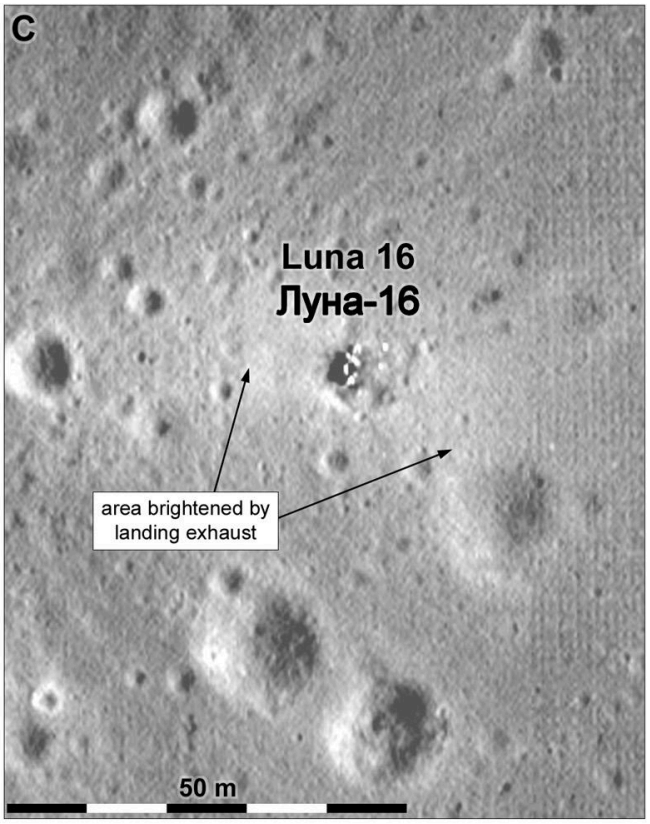
February 22, 2025 - #moon #Luna16

Not much was said about this at the time, but more recently we have learned that the pictures did in fact reveal some details. Apparently, bright glints off rocks could be seen faintly, but the image quality was too poor for them to be useful. That's too bad. I think that if we could get the original data off the big data tapes (which would almost certainly be in the Lenin Library), modern image processing could probably salvage something from them.

February 22, 2025 - #moon #Luna16

But why land in the dark? I note that they spent 3 days in lunar orbit before landing, so they arrived in orbit before sunset. Maybe there was just not enough time to check everything before sunset and be ready to land. Tracking during those 3 days helped improve knowledge of mascons, the gravity anomalies which complicate low orbit operations. But we don't really know why this happened the way it did. I close with another site map and a closeup LRO image composite.





A map of the landing area of Luna 16 (the base image is a Soviet-era map which I have marked up). and an LRO image composite showing the lander on the surface. It is surrounded by a fuzzy bright spot, like most landed spacecraft.

February 23, 2025 - #moon #Zond

Luna 16 was followed by Zond 8, the last test flight of this type of spacecraft. It followed the pattern of a flight around the Moon and back, not going into orbit (like Artemis 2, not Apollo 8 and 10). NSSDCA provides a few details:

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1970-088A

The photography was much better on this mission with large images taken of a full disk and a lower altitude strip of the farside highlands. Don Mitchell has a good selection:

http://mentallandscape.com/C_CatalogMoon.htm (halfway down).

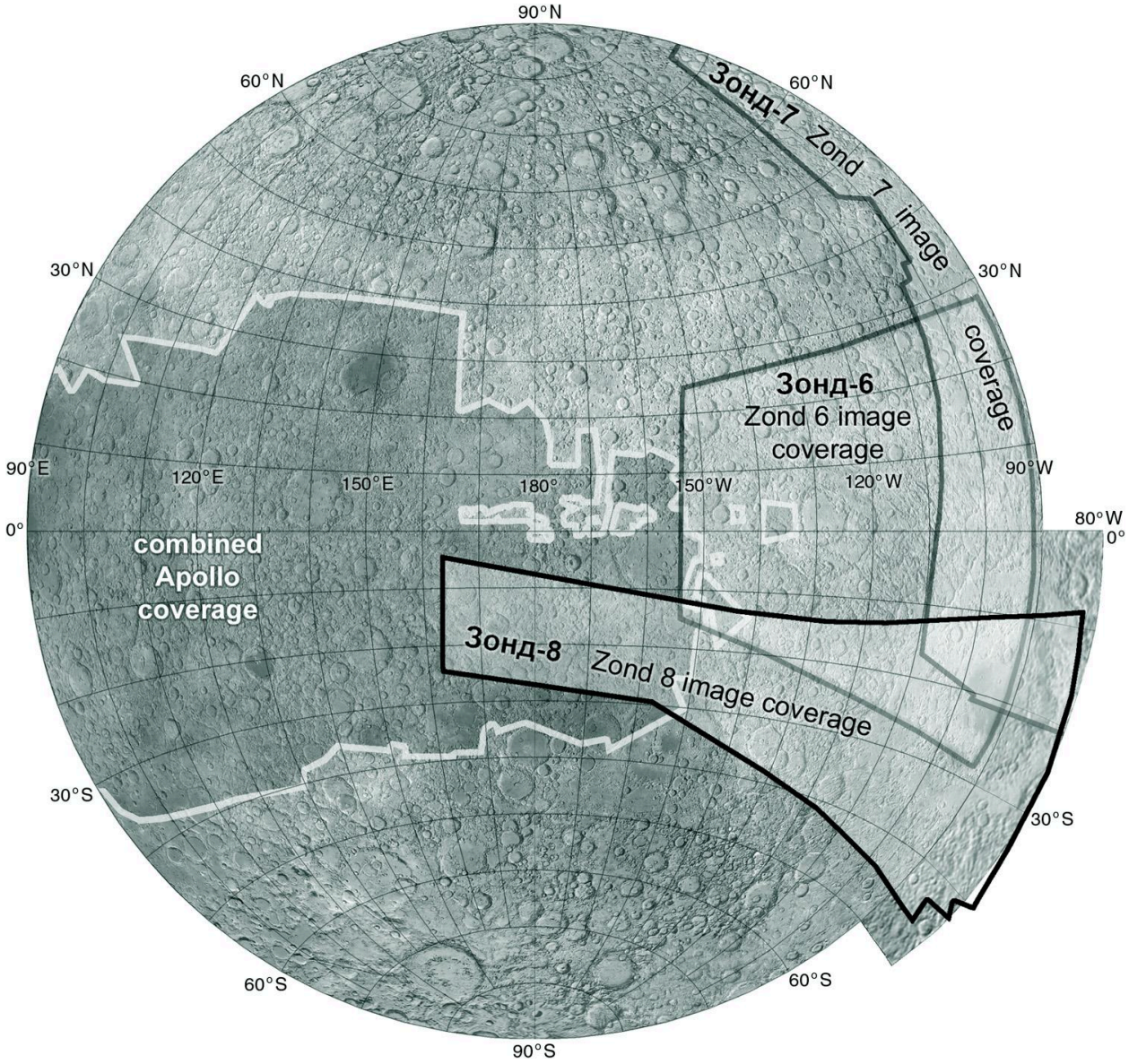
February 23, 2025 - #moon #Zond

Kira Shingareva came to Houston one year with CD-ROMs of scanned Zond 8 images. A set went to LPI, I got a set, there may have been others (I was her driver and guide on that trip). The scans revealed something interesting: the images were good quality but had a few scratches. They had not been protected as well as Apollo negatives were (after being developed they were copied and the originals archived for decades with all work done on copies). Only recently were they scanned again.

February 23, 2025 - #moon #Zond

This map shows the Zond 8 image strip coverage, the Zond 6 and 7 image areas, and the Apollo image coverage (omitting only Apollo 13 and the global views taken during departure). Soviet planetary geologists made a nice set of maps of the Zond 8 area with relief drawings and a geological interpretation. Until LRO these were the best images of that region. A limb profile gave another look at topography in the South Pole-Aitken basin (see Zond 6 notes).

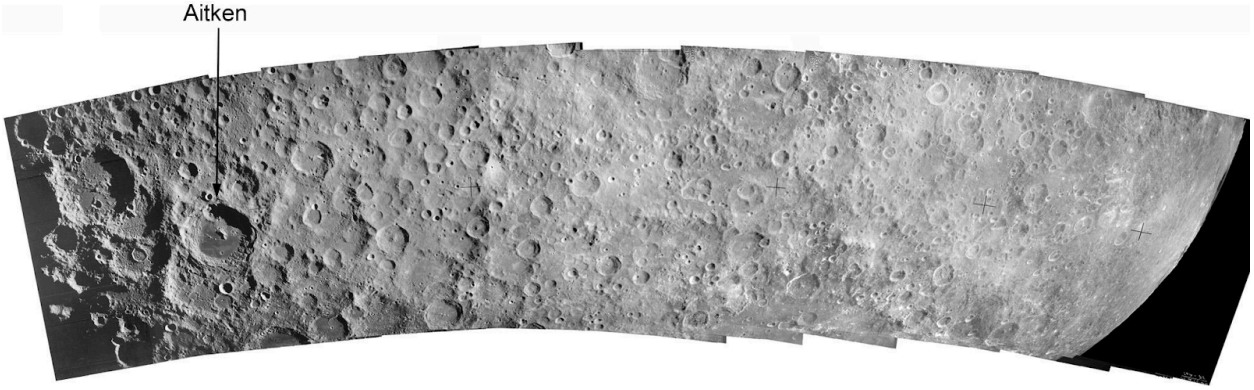
(Image on next page)



A map of the lunar farside with locations of Apollo images (an outline of the entire Apollo image set except for Apollo 13 and global views during departure), and the Zond 6, 7 and 8 images. Between them they cover the entire equator and much of the mid-latuudes.

February 23, 2025 - #moon #Zond

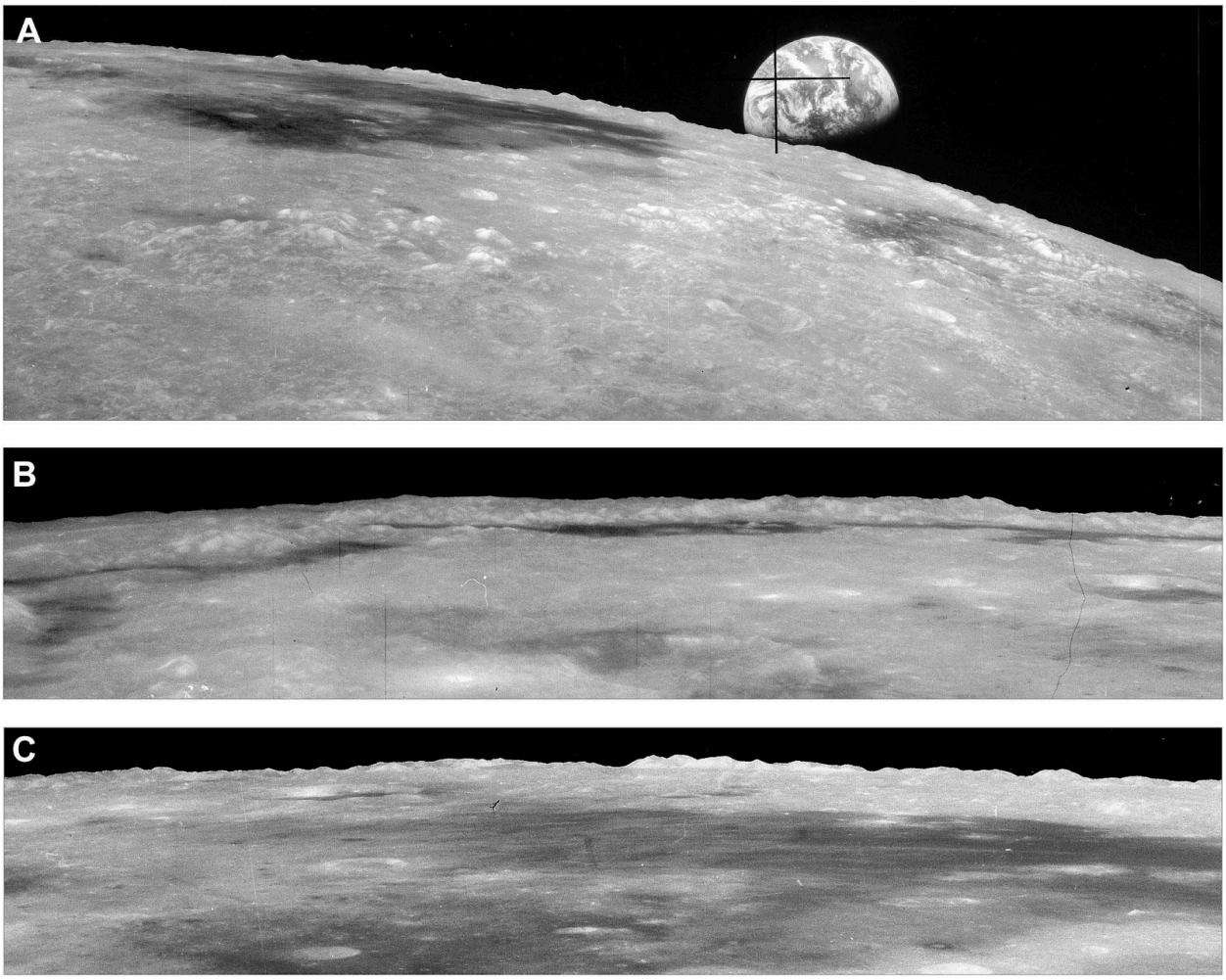
Some Zond 8 images now. This is a very reduced version of the high resolution image swath.



A greatly reduced version of the long swath of images from Zond 8, extending from the terminator west of Aitken crater to the limb near 80 degrees west.

February 24, 2025 - #Zond

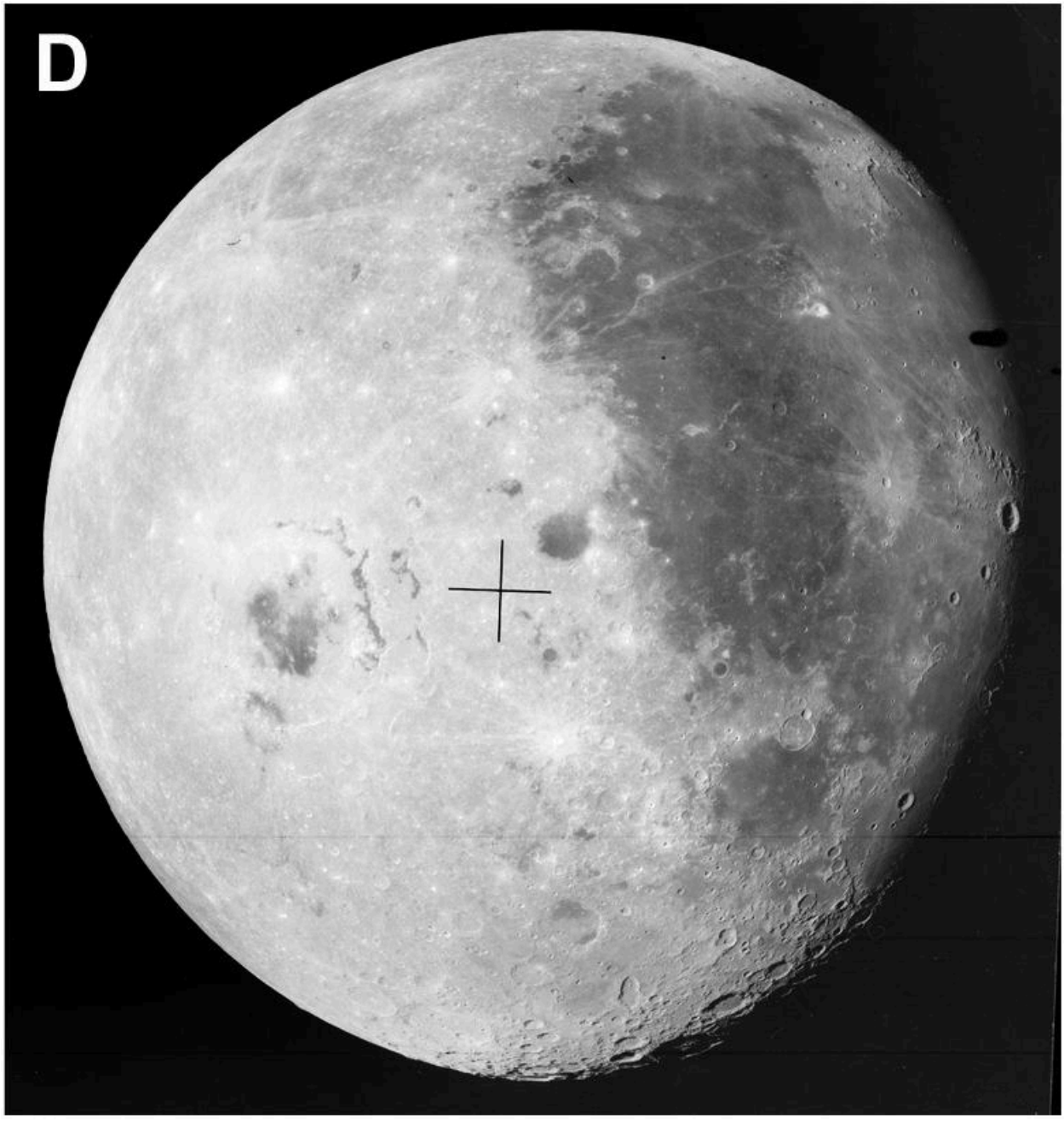
These are views over Mare Orientale looking east with the peaks of the Cordilleras on the horizon. I have done no cosmetic cleanup to these images. #moon The Earth has a big reseau cross over it.



A greatly reduced version of the long swath of images from Zond 8, extending from the terminator west of Aitken crater to the limb near 80 degrees west.

February 24, 2025 - #moon #Zond

Lastly, this is a fine view of the Orientale area, with the limb at left crossing the South Pole-Aitken basin and giving a nice topographic profile of the basin.



The moon seen by Zond 8 . Grimaldi crater is at the middle near the reseau cross. Mare Orientale is to its left. The dark plains of Oceanus Procellarum cover much of the eastern (right) side of the image.

February 25, 2025 - #moon #Luna17 #Lunokhod1

Now we move on to one of the triumphs of Soviet lunar exploration, Luna 17 and its companion, Lunokhod 1, the first remotely operated rover on another world. Its mission is briefly described here:

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1970-095A

(but its comment on cameras is wrong). As usual Don Mitchell has a great set of images here:

http://mentallandscape.com/C_CatalogMoon.htm

(also for Zond 8).

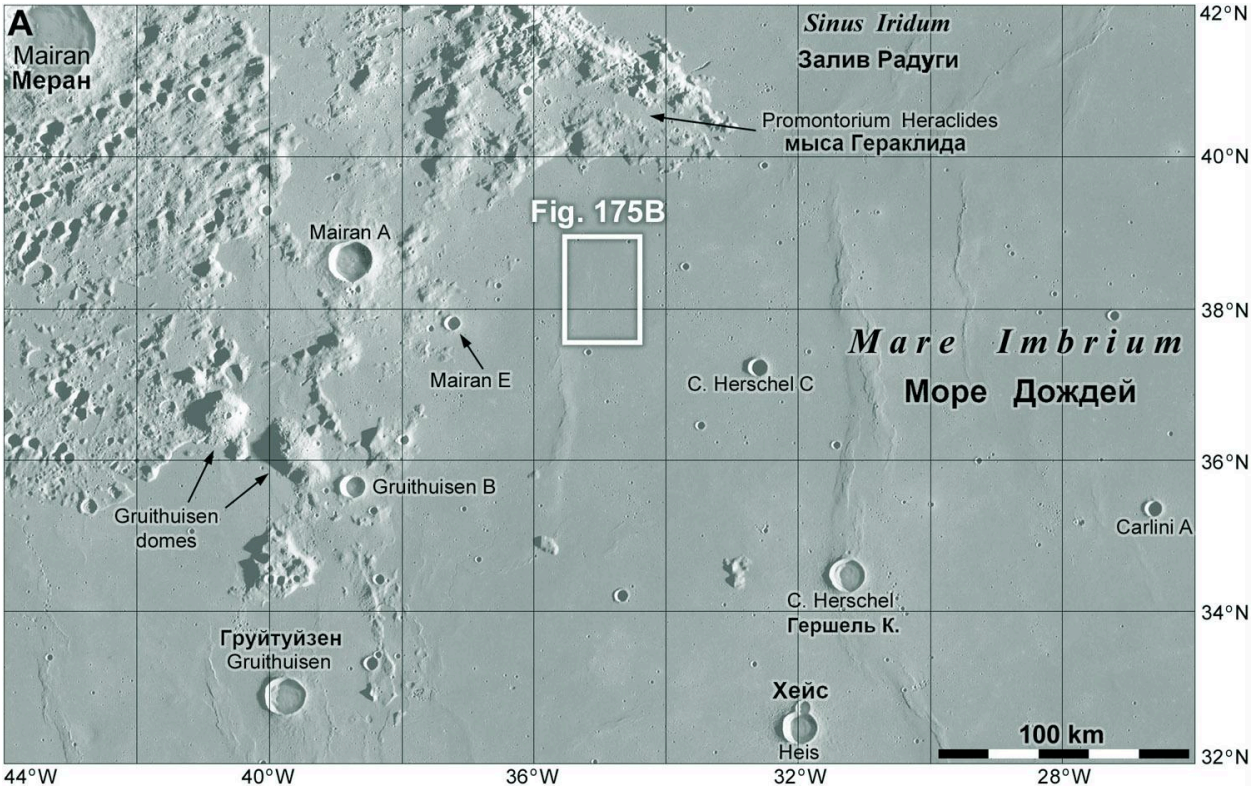
And more panoramas here:

https://www.planetology.ru/panoramas/lunokhod1.php

There is plenty to look at here. Tomorrow... where is it?

February 26, 2025 - #moon #luna17 #lunokhod1

This is the region where Luna 17 landed with its precious cargo, Lunokhod 1. It's at the western edge of Mare Imbrium where it merges with Oceanus Procellarum, and not far from the Gruithuisen Domes where a CLPS mission will be heading next year. The early landers were sent to western equatorial sites (for a relatively easy vertical descent) and the sample return missions to the east as mentioned earlier. Lunokhods went to northern mid-latitude sites. Why?



A map of the landing area for Luna 17 and its rover, Lunokhod 1. It lies near the edge of Mare Imbrium, one of the Moon's largest dark lava plains. It is not too far from some mountainous areas. Will any peaks be visible?

February 26, 2025 - #moon #Luna17 #Lunokhod1

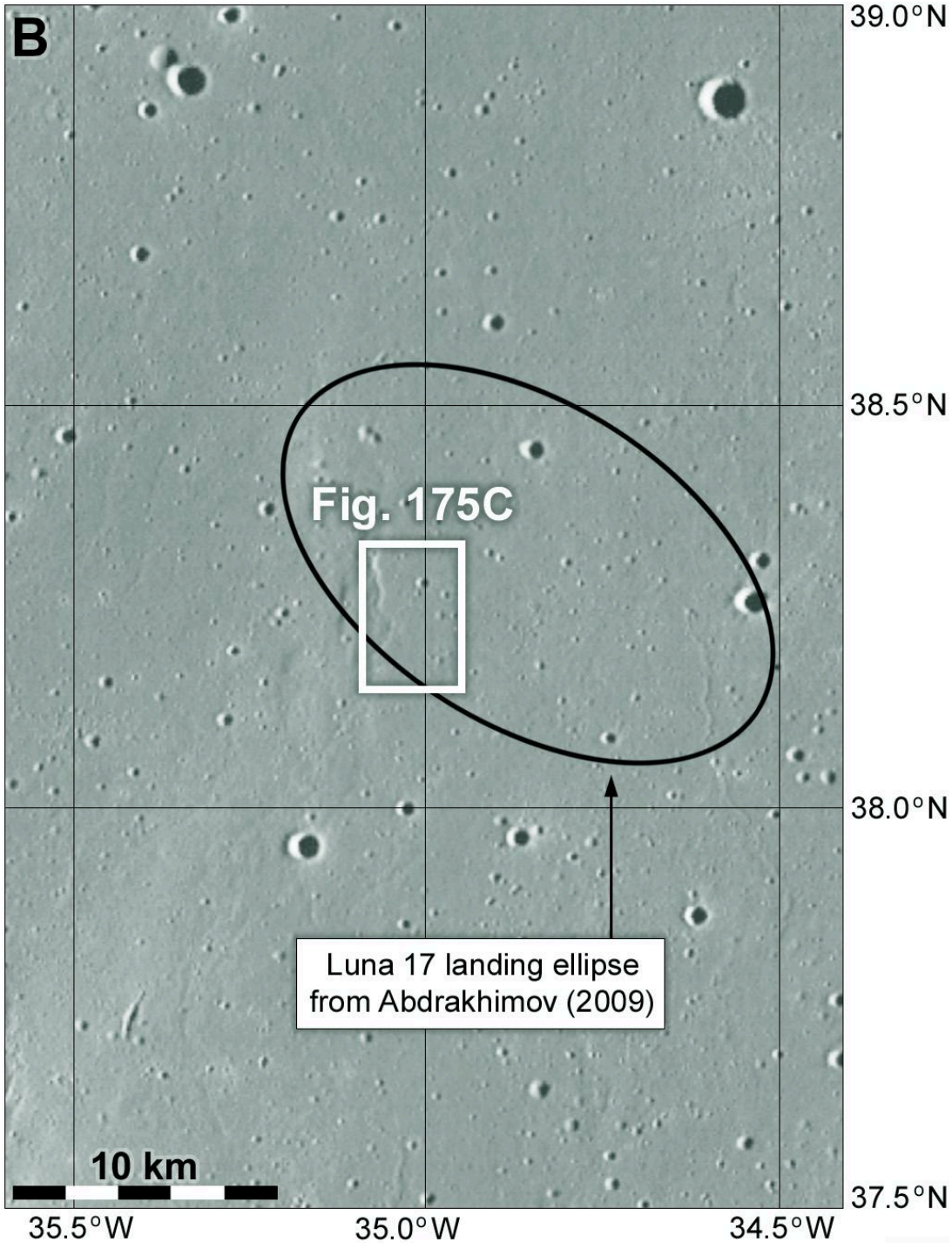
I have never seen a reason for the Lunokhods to go to northern mid-latitudes. Is it fair to generalize when there were only 2? There was actually a third, lost in a launch accident in February 1969, which was apparently supposed to go to the Lunokhod 2 site which we will see later. I suspect the mid-latitudes were chosen for their mid-day temperatures (lower than at the equator) which would matter for these long-lived missions. All 4 Chinese landers have done the same.

February 27, 2025 - #maps #moon #Luna17 #Lunokhod1

My last map has a box labelled 'Fig. 175B'. Just a reminder that these are placeholders for figure numbers in a future project which I will be talking about later in the year.

Let's zoom in on that boxed area. This map shows the landing ellipse shown in a 2009 publication. A smaller box zooms in towards the landing site. A wrinkle ridge is just visible within it.

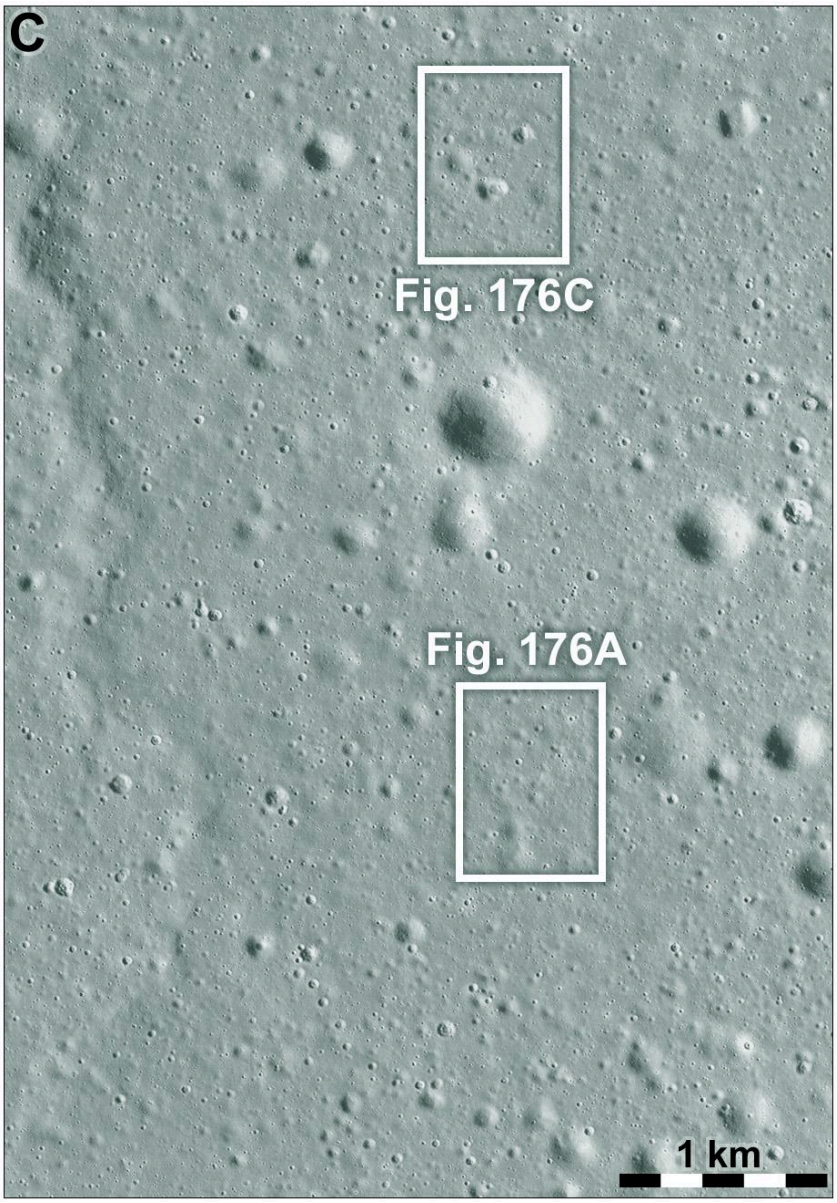
(Image on next page)



The landing site of Luna 17 is within the box in this map, which also shows a landing ellipse taken from a 2009 publication. The ellipse is about 12 by 20 km across.

February 27, 2025 - #maps #moon #Luna17 #Lunokhod1

Zooming in again we see the ridge very clearly. I will have something to say about it soon. Among the scattered craters are two more boxes. The lower one shows the position of the lander. The upper one shows the final resting place of the rover. I make sequences of maps like these so people can easily find a small spacecraft in a large image (LRO NAC images are 50,000 pixels long and 5000 pixels wide, that's a lot of pixels to search through).

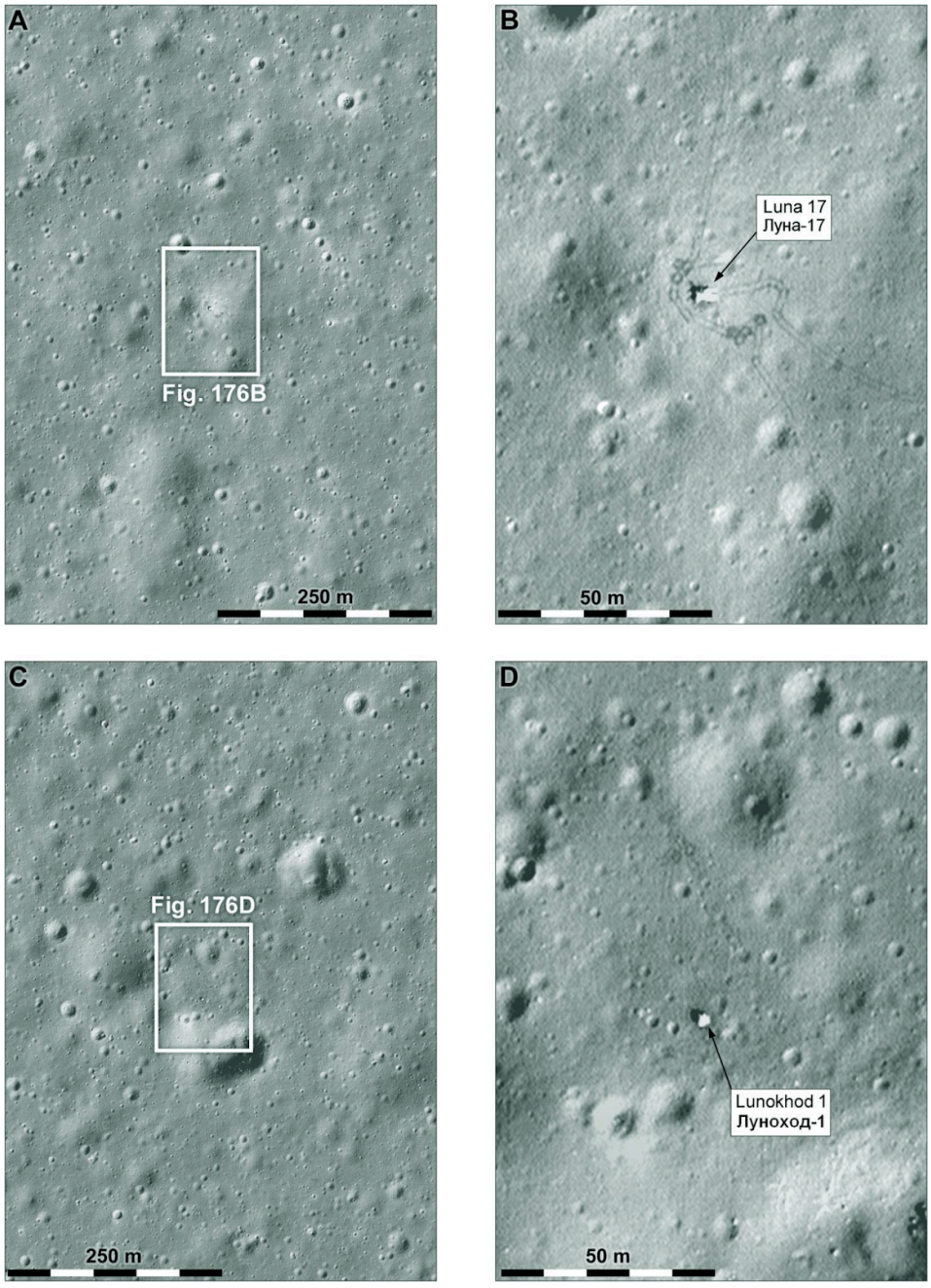


A closer look at the Luna 17 landing site. This map shows a wrinkle ridge on the basalt plains and many craters large and small. Two boxes zoom in to the lander (bottom box) and final position of the rover (top box).

February 28, 2025 - #maps #moon #Luna17 #Lunokhod1

Finally that zoom-in sequence leads to this. Box A in the previous post refers to A here, which takes us to B with the lander itself. Box C in the previous post refers to box C here and the link to D, the rover's final parking place. Tracks from Lunokhod's wheels are visible around Luna 17 and the parked rover. We will be following the traverse in a set of maps like the Apollo EVA maps. But first, let's consider how we know where Luna 17 landed.

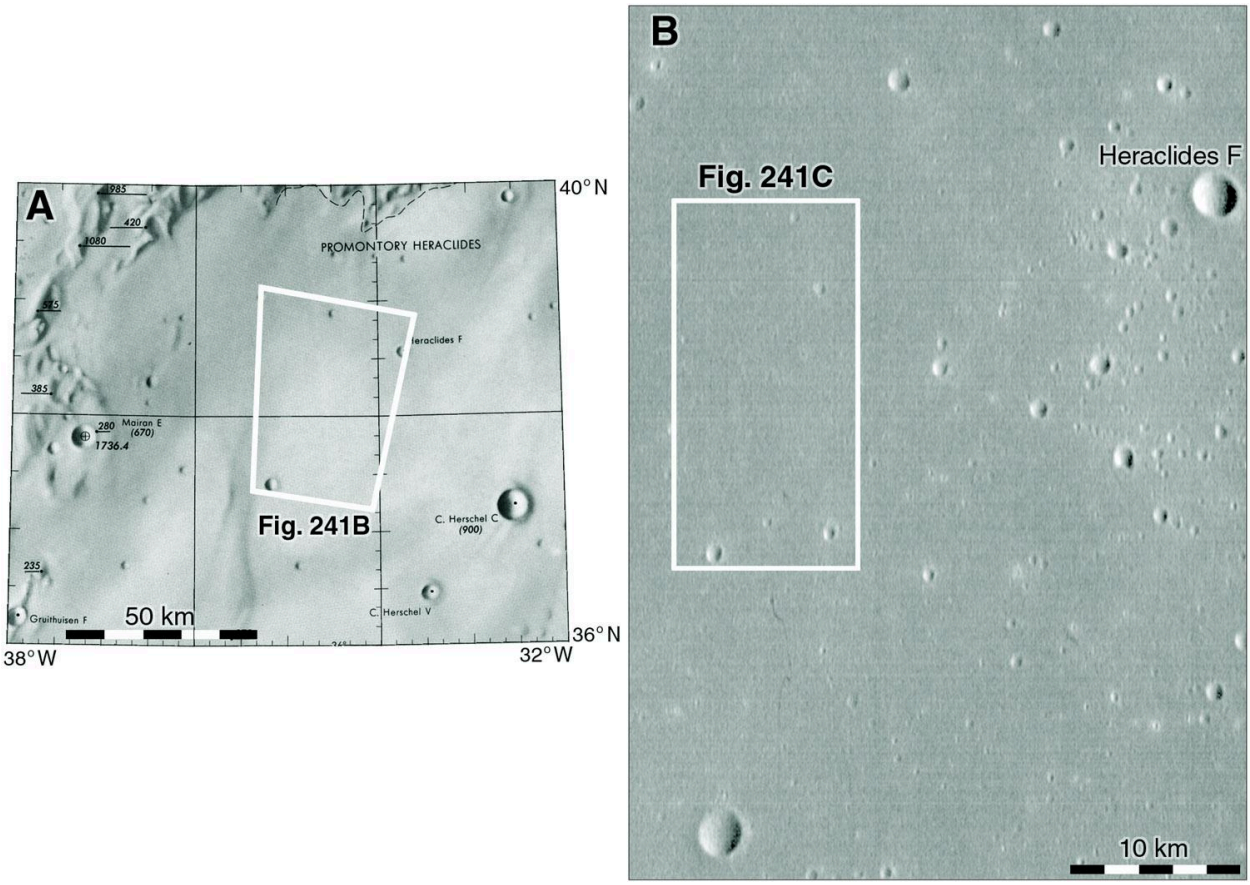
(Image on next page)



Four maps which show the locations on the Moon of Luna 17 and Lunokhod 1. They follow the previous 3 posts, going from a broad region to a small area - the post before this - containing two boxes labelled A and C. That A refers to the top left map here, which leads to B, showing Luna 17 on the surface. That C leads to the bottom left map here which leads to D, showing Lunokhod 1. Wheel tracks are visible around the lander and rover.

March 1, 2025 - #maps #moon #Luna17 #lunokhod1

Now it's very clear where Luna 17 landed. we have LRO images good enough to show the lander and rover and the wheel tracks. But what did we know before LRO? My first Moon atlas came out before LRO (so it was swiftly rendered out of date and some of my speculation was shown to be wrong). This illustration shows what I thought about the landing site in about 2005 when I was doing that work. Tracking and orbit data gave us a position accurate to within about 10 km.

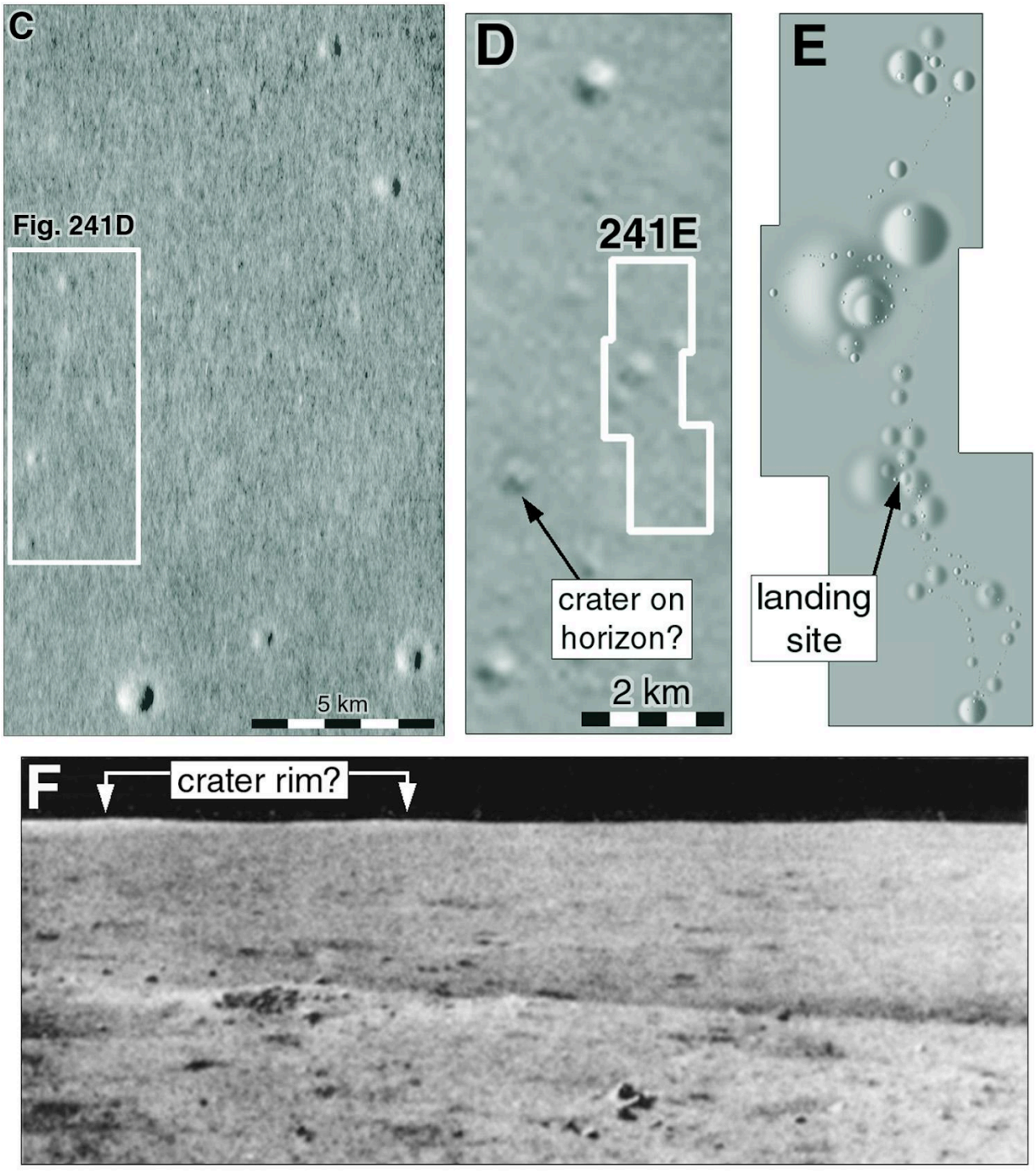


Pre-LRO maps showing the Luna 17 landing site as then suspected. The picture at right is an Apollo 15 oblique image - the best image available before LRO.

March 1, 2025 - #maps #moon #Luna17 #lunokhod1

Here we zoom in more. C is the best image we had, an Apollo 15 oblique Hasselblad photo, roughly rectified. Another clue came from a Soviet Lunokhod 1 route map which showed many craters. Image E is a shaded relief depiction of those craters. D was my attempt to match E with C. You can see how hard it would be to get it right. As an extra bit of the puzzle I thought a very subtle feature on the horizon in a Lunokhod 1 image might be a crater rim.

(Image on next page)



The Luna 17 landing site in pre-LRO data. At top left is the Apollo 15 image. At top right is a shaded relief drawing based on a Soviet route map for Lunokhod 1. Between them is an attempt to match them, but it's almost impossible to get it right. One extra detail: at the bottom is a bit of a Lunokhod 1 image. A very subtle feature might be a crater rim, which I thought I could match in the orbital image.

March 1, 2025 - #maps #moon #Luna17 #lunokhod1

Here is that Soviet-era map. My shaded relief version, based on this, shows a large crater near the middle - the largest one in the map. Naturally I tied to match it to the orbital data. But it doesn't really exist if you check the LRO data, so I can use that as an excuse for not getting it right. Maybe it was a very subtle depression rather than a distinct crater.

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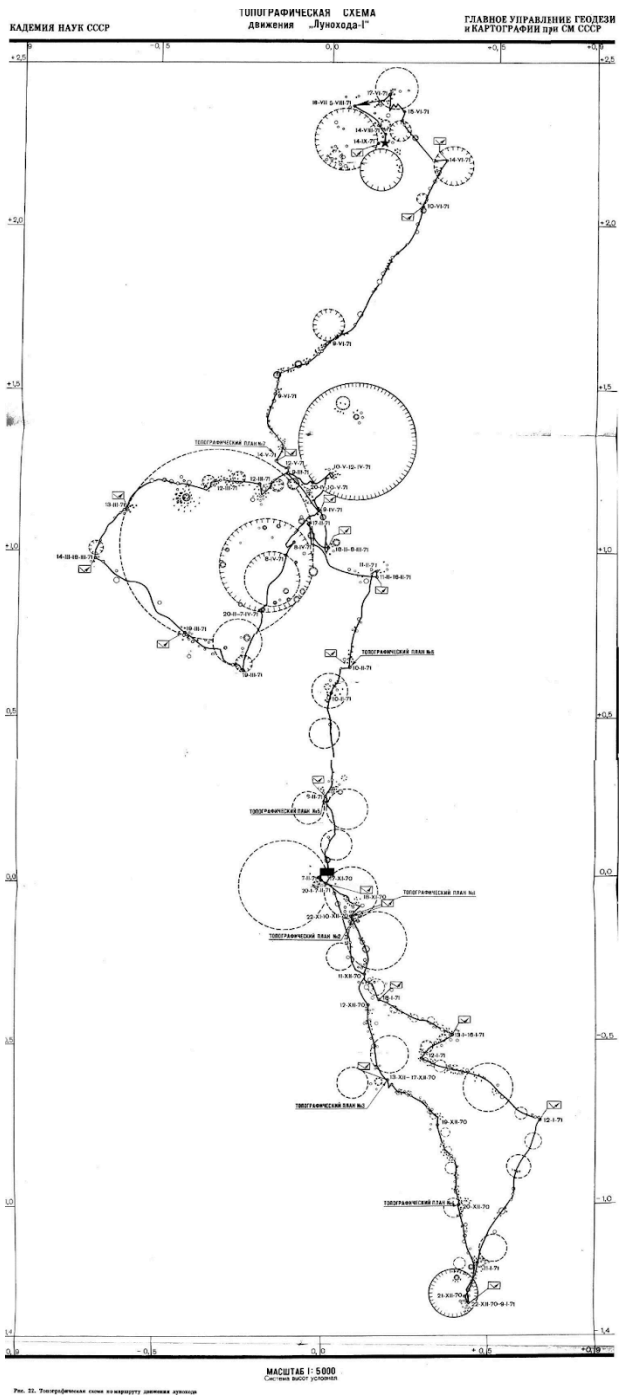

A Soviet-era map of the Lunokhod 1 route. The largest crater, just above the middle, was important for me to try to locate the site. But it doesn't really exist.

March 3, 2025 - #maps #moon #Luna17 #lunokhod1

I was distracted last night by current events on the Moon. Continuing our story of Soviet lunar missions, we were looking at where Luna 17 might be. There is one more bit of information about the location which we have not considered, but I will come back to it later. So on with Lunokhod 1. I will show the traverse in a series of maps like those we saw for Apollo, and this map serves as an index to them. Figure numbers refer to a future project.

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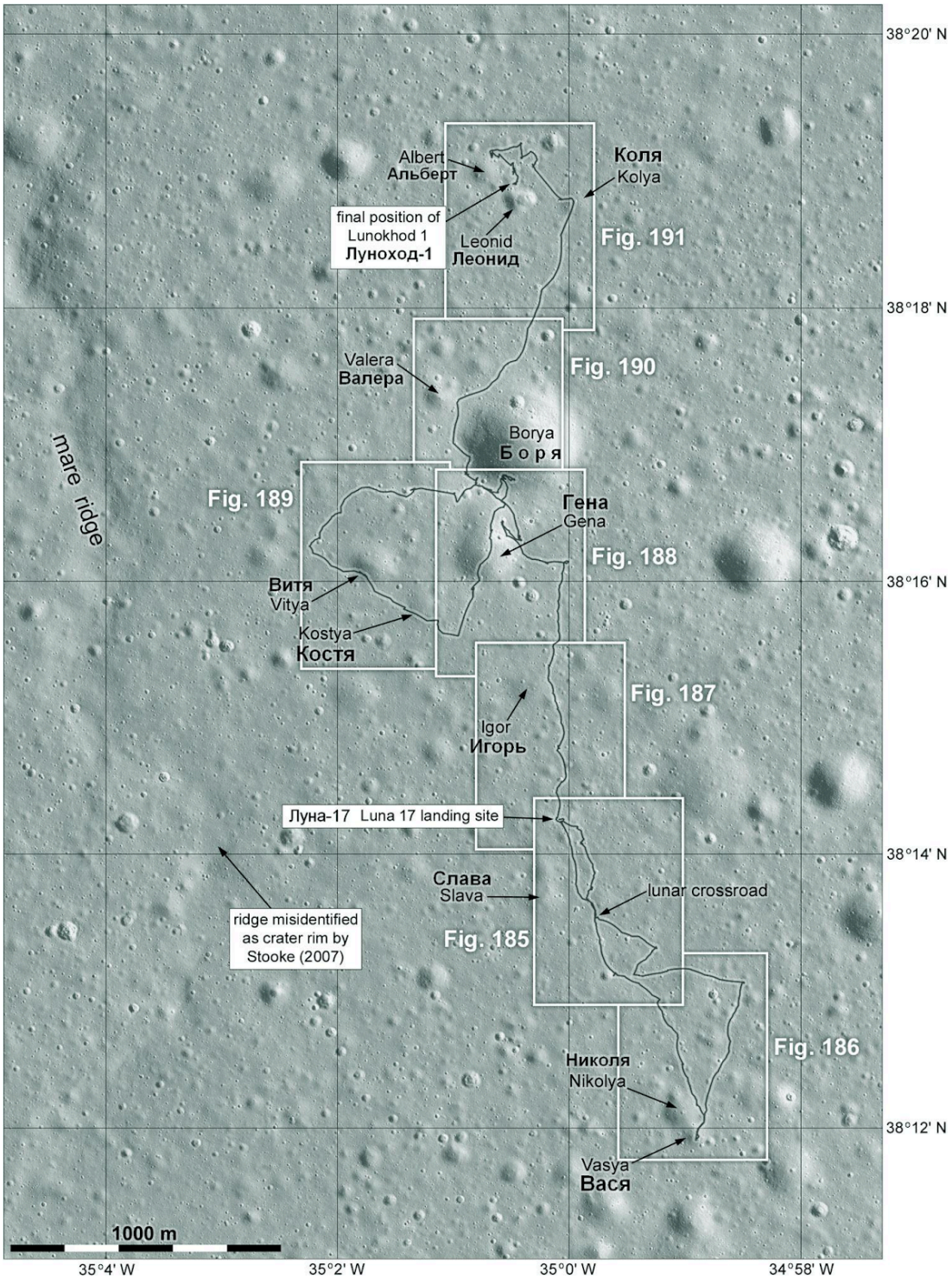

A map of the Lunokhod 1 traverse area with rectangles showing a series of more detailed maps following this post. Also shown are names of craters, not used at he time but given recently on a new Russian map. They are the first names of people associated with the mission.

March 3, 2025 - #moon #Luna17 #lunokhod1

A few things to say - crater names were not used at the time but come from a new Russian map and are official. They are people associated with the mission. The ridge at left is perhaps what I saw as a crater rim. Notice the lat-long labels are degrees and minutes. Usually I use decimal degrees but my policy has been to match contemporary documents. But looking at this, I have decided to change back to decimals (later).

March 4, 2025 - #maps #moon #Luna17 #lunokhod1

This map is the first one covering the Lunokhod 1 traverse. The previous map is an index to this set. This map shows both a drive to the south from the lander and part of the return journey. Dates are from the Soviet original posted recently. The 'plan' labels refer to places where multiple images allowed for detailed mapping of areas of interest, and they will be shown later. See the note about laser detections. We will come back to that.

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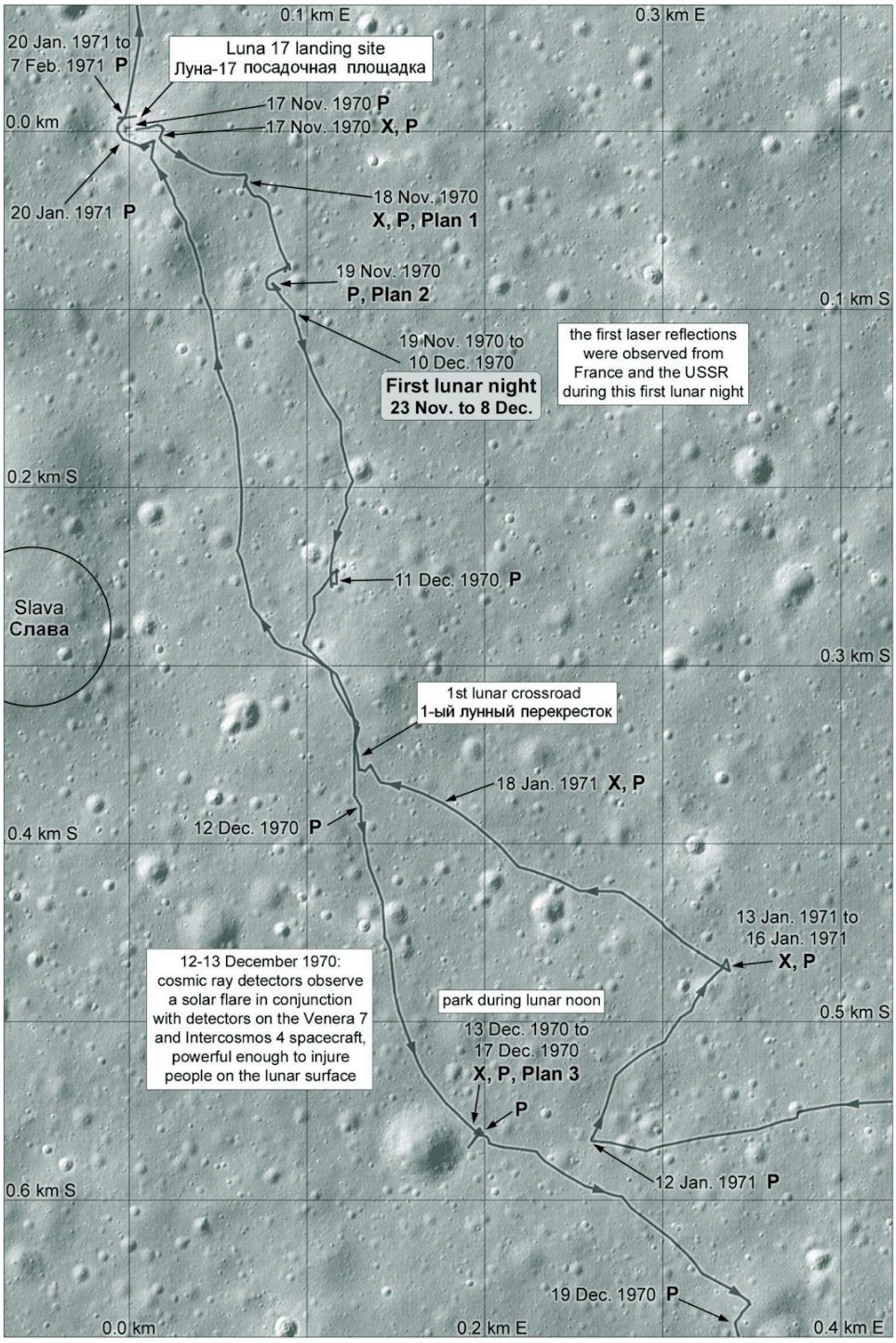

The first map of a set showing the Lunokhod 1 traverse. The lander is at the top left of the map. The rover was driven mostly south after leaving the lander, commanded in real time by drivers watching TV images. This map also shows part of the return journey as the rover zig-zagged back to the north, eventually meeting its old tracks and following them part of the way back to the lander.

March 5, 2025 - #moon #Luna17 #lunokhod1

The letter P symbol on the Lunokhod 1 map shows where panoramic images were taken. The X symbol shows where the X-ray surface composition instrument was used. If you follow the dates carefully you will see that Lunokhod started work a day or two after sunrise, operated for just a few days, then took a nap over the middle of the lunar day (e.g 13-17 December), drove for a few days and shut down a day or 2 before sunset. China's Yutu rovers did the same.

March 5, 2025 - #maps #moon #Luna17 #lunokhod1

This is the second Lunokhod 1 map, the southern end of the drive. The first lunar night was spent not far from the lander. The second was at the southern point here. On the third day the rover was driven quickly back to the lander, testing navigation. Remember they were driving effectively blind. There were no great images like these we have now. Just being able to get back to the lander quickly was an accomplishment.

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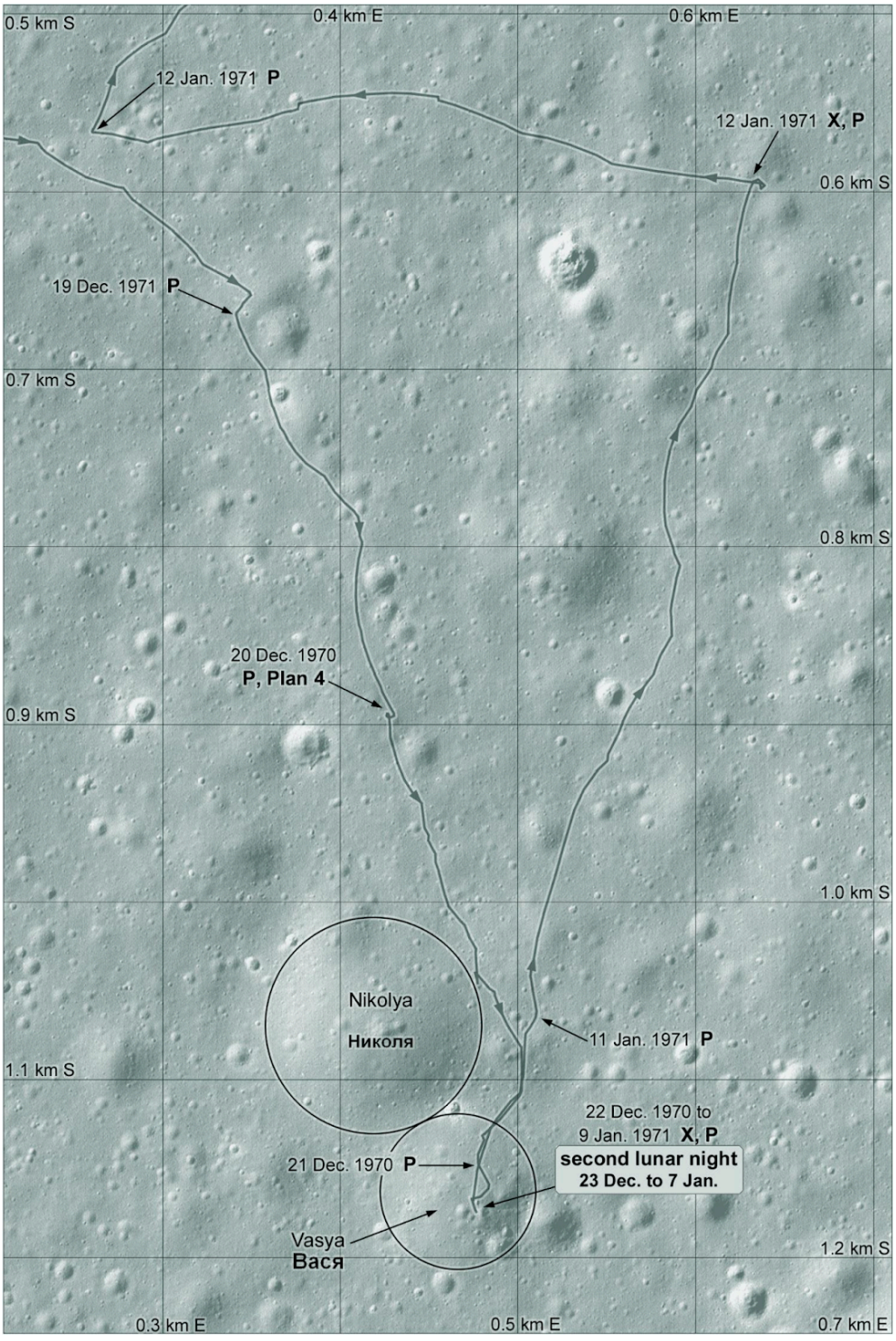

The second Lunokhod 1 map. The rover was driven south from the place where the first map ended until it reached a crater (now called Vasya) where it spent the second night. On the third day it drove back to the lander.

March 6, 2025 - #maps #moon #Luna17 #lunokhod1

Lunokhod 1 spent its third night close to the lander - there wasn't room to label it on the first map but here it is made clear. The lander was imaged from several directions. Then the rover drove rapidly northwards. The mission team had spotted distant hills on the northern horizon and decided to head for them, not to reach them but at least to get a closer look. We'll get to that later.

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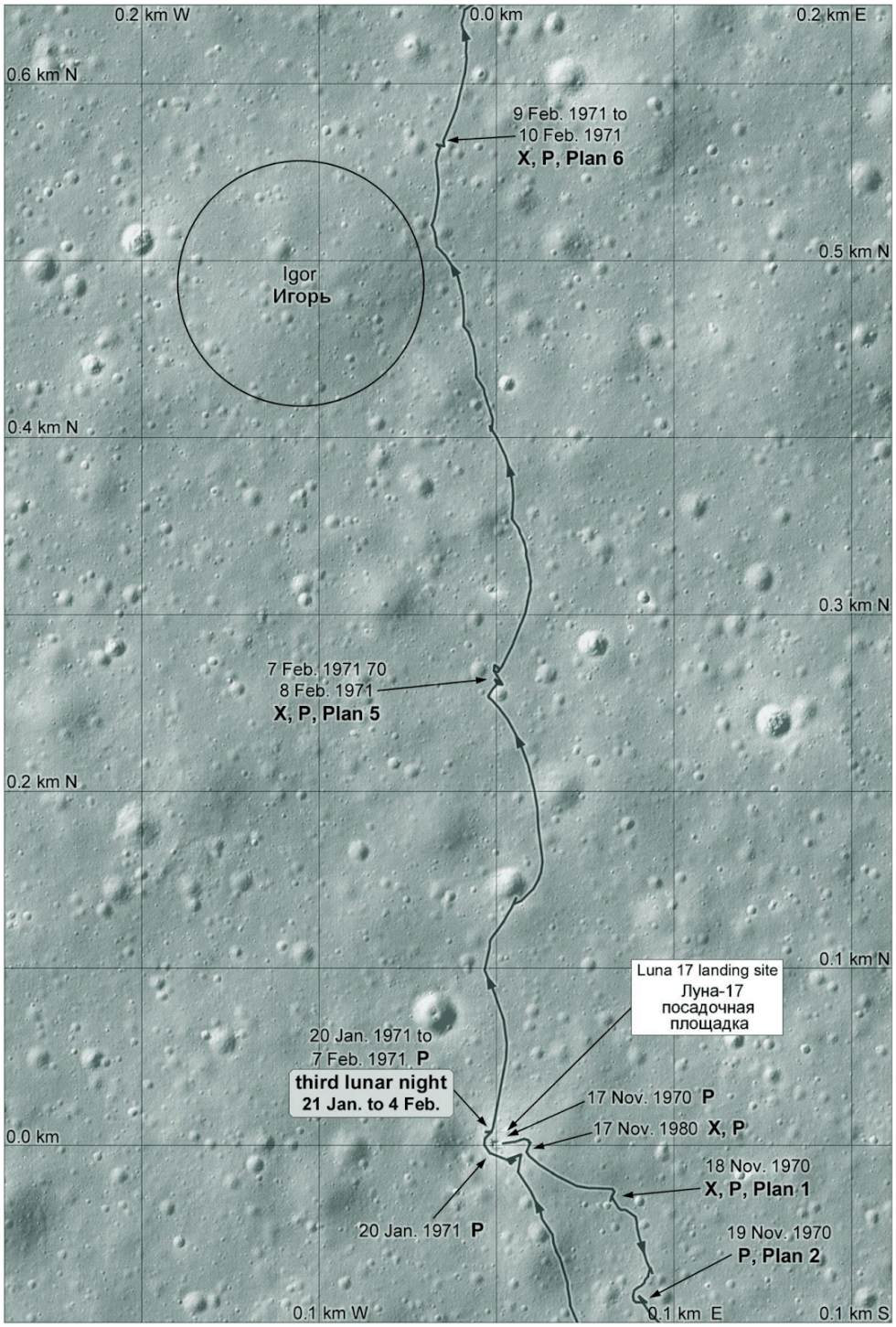
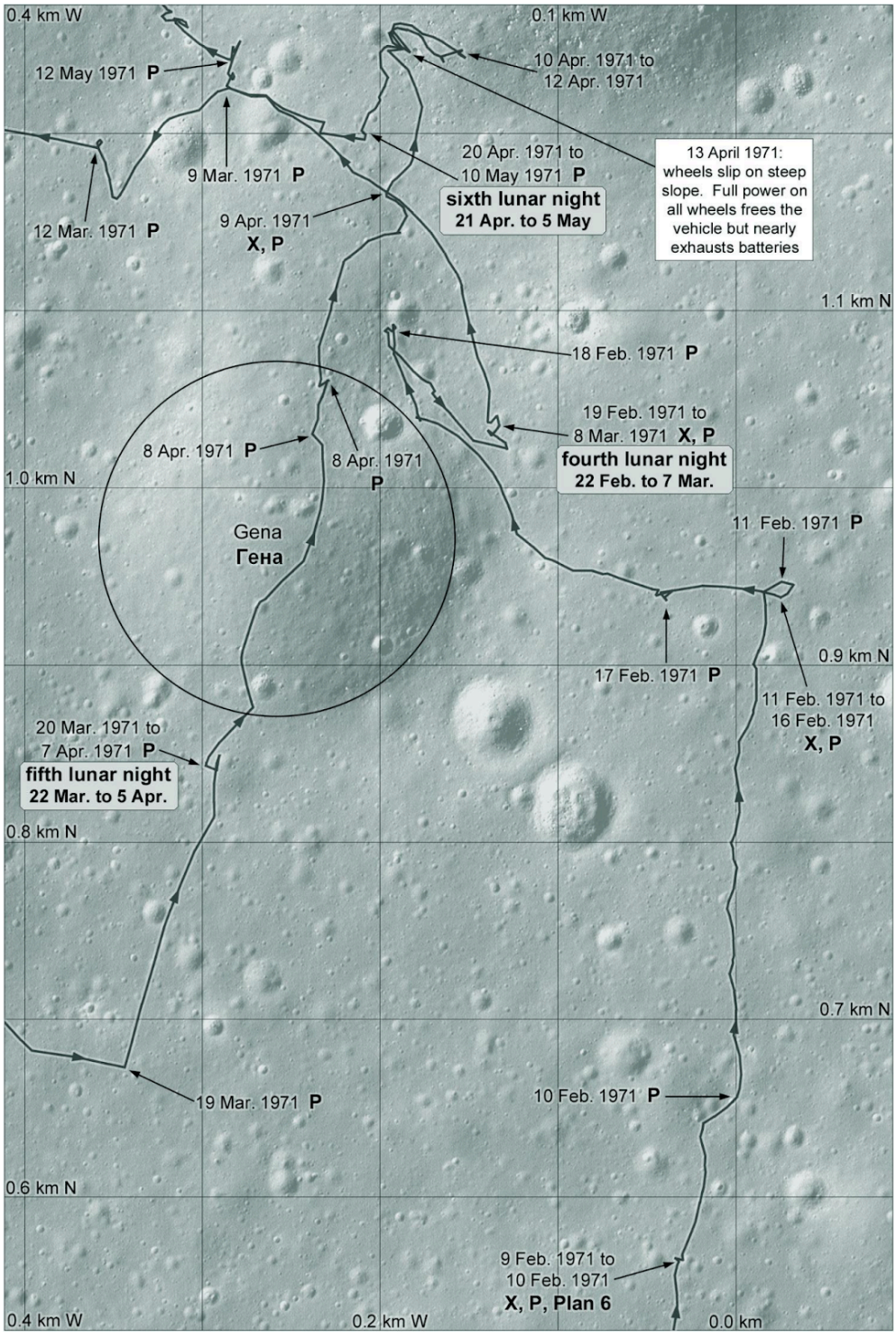


The third map of the Lunokhod 1 traverse. The 3rd day of driving brought the rover back to the lander, where it parked for the night. Then it drove rapidly north. This map has the lander in the middle near the bottom edge, and a route during the morning of day 4 which runs up the middle of the map to the top edge, all in just a few Earth days.

March 7, 2025 - #maps #moon #Luna17 #lunokhod1

We come to the 4th map of the Lunokhod 1 mission traverse, and there is quite a lot to say about it. The rover was driven north on the morning of lunar day 4 and paused for a few days around lunar noon in mid-February. Then it moved northwest to a spot on a crater rim on 18 February, turned back and stopped for the night on the 19th. On day 5 the rover drove a loop to the west, which runs into the next map, and back into this one.

(Image on next page)



The 4th map of Lunokhod 1's traverse. The rover entered it from the south on lunar day 4. On day 5 it drove a loop out to the west, off this map, and back. On day 6 it entered a large crater and had trouble getting out. On day 7 it departed through the top edge of this map.

March 7, 2025 - #moon #Luna17 #womensday

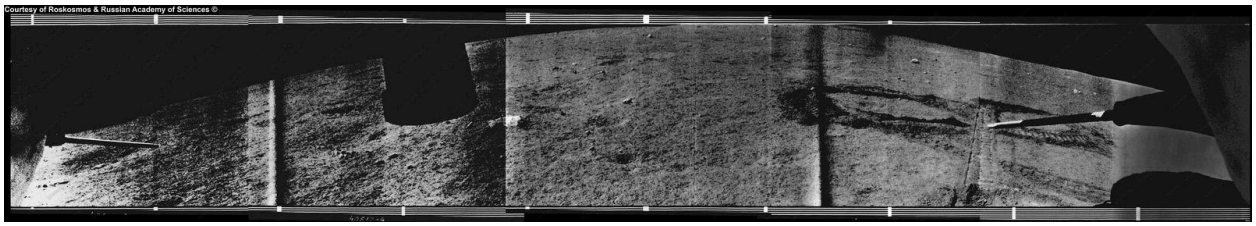
After that westward loop Lunokhod 1 drove on day 6 through the shallow crater Gena and into Borya, the largest crater. It had trouble getting out and stopped to recharge. On lunar day 7 it drove north again, around Borya.

Just after the 4th night, on 8 March... well, that is International Women's Day, a holiday in the Soviet Union. The rover team promoted a figure 8 made by the rover's wheels (two adjacent turns in place) as a memorial to women for that day...

March 7, 2025 - #moon #lunokhod1 #womensday

... This story about Women's Day is also told about a marking made by Lunokhod 2, but the mark in question was made about 2 months before the day that year.

Where is this? As far as I can tell it's this marking. And I think it was made at that point I mentioned on 18 February. That was only an Earth day before the rover stopped for the night, easy to remember on the next morning. Enjoy the day this year with a special person (advice does not apply in the US).

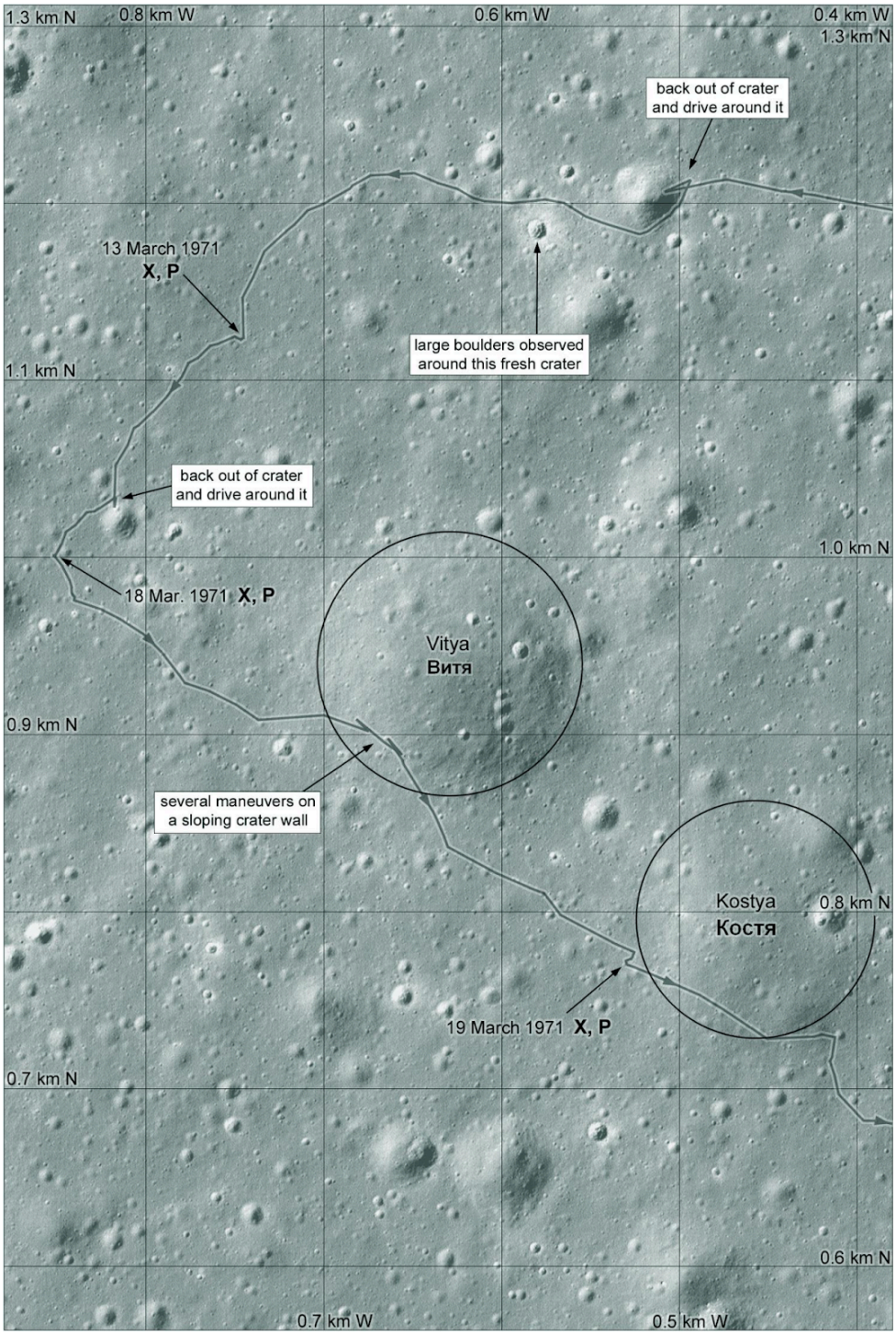


A panorama made by Lunokhod 1 showing at the right edge a pair of circles in the rover tracks made by two adjacent turns in place. I think this 'eight' is the commemoration of International Women's Day.

March 8, 2025 - #maps #moon #luna17 #lunokhod1

Today we see the fifth map of the Lunokhod 1 traverse. This is the big loop to the west of the previous map. It only took a few days. Compare this map with the Soviet traverse map I posted earlier. This loop was mapped as if it roughly followed the rim of a large subdued crater. Looking for that crater - which doesn't really exist - took up a lot of my time and gave me an incorrect location before LRO found the site.

(Image on next page)

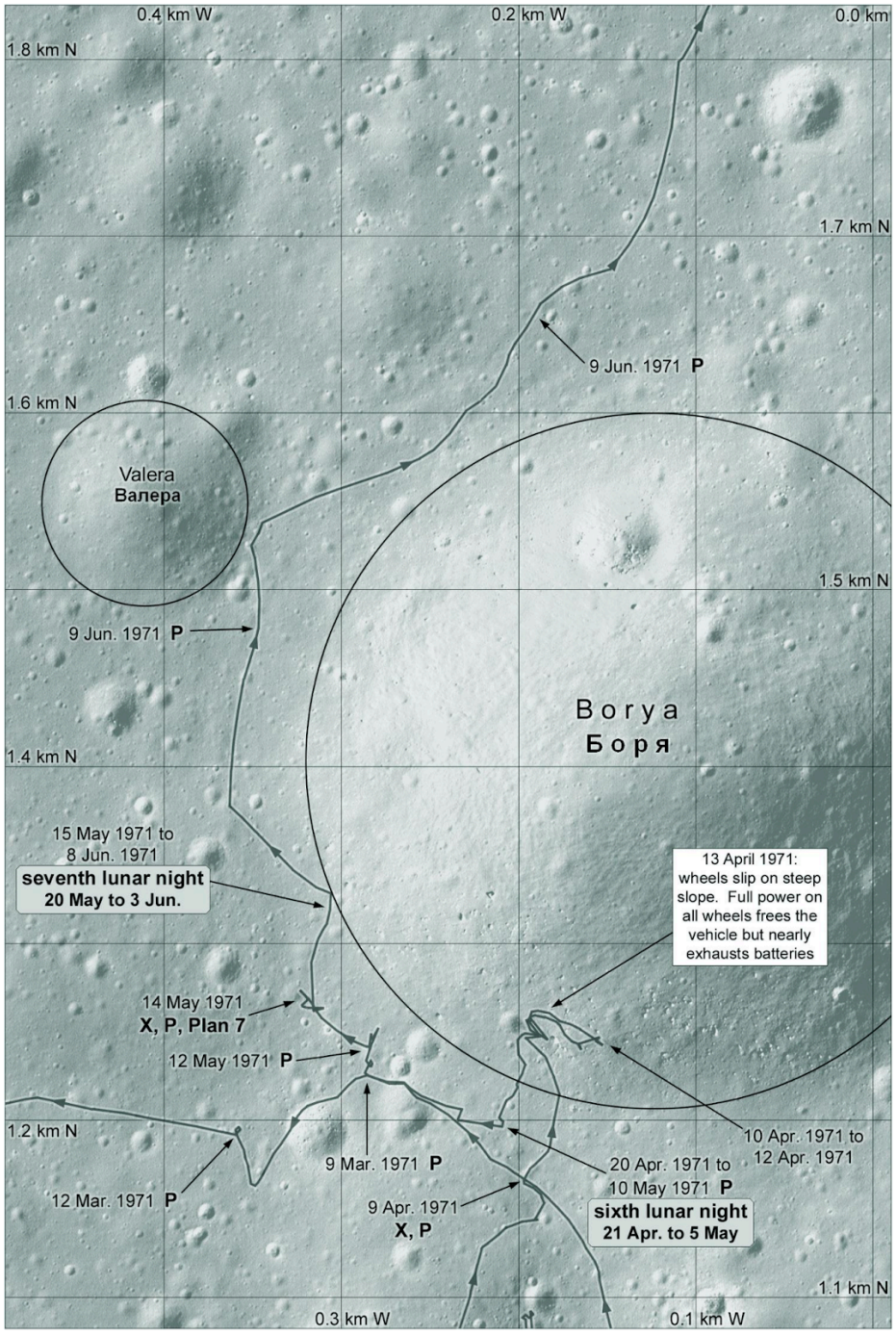


The 5th section of the Lunokhod 1 route map. Here the rover is following a looping path west of the previous map. The Soviet map posted earlier represented this as a large shallow crater. I tried to find it to locate the rover but it was not easy to find (because it doesn't exist) and it led me astray.

March 9, 2025 - #maps #moon #luna17 #lunokhod1

After that loop Lunokhod 1 returned to the vicinity of Borya crater, and it is now that it enters the crater. That may have been a mistake, and it was certainly hard to get out. The rover had to use full power to escape the steep slope, running down the battery. When it was back on level ground it rested to recharge and then went into its sixth night. It didn't go far in day 7 and spent the next night on the rim of Borya.

(Image on next page)



The 6th map of the Lunokhod 1 route. The rover enters the map area from the south, and drives into a big crater, Borya. It has trouble getting out but does eventually. Then it rests to recharge batteries, and on the next lunar day it moves only a short distance along the crater rim. The day after that, the 8th lunar day, sees it drive rapidly north and off the top of the map.

March 10, 2025 - #maps #moon #luna17 #lunokhod1

This is the 7th and final map of the Lunokhod 1 traverse. The rover was driven north from the previous map area and into a cluster of craters, some of which were given names. It reached its northernmost point on 17 June and parked for the 8th night nearby. Systems were apparently deteriorating and the next day saw only a short drive near Albert crater. The next lunar day, the 10th, was also marked by short drives and many twists and turns.

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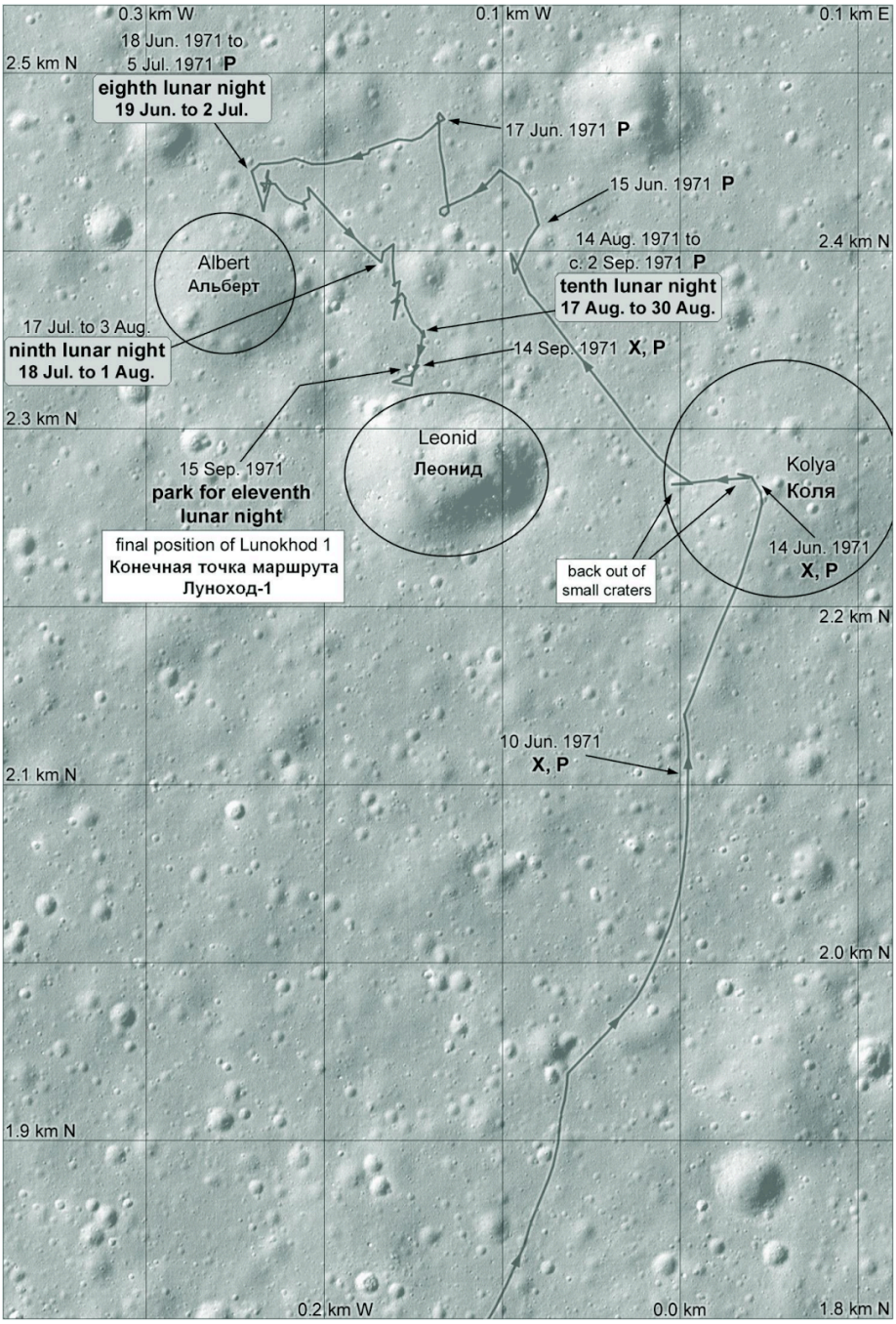


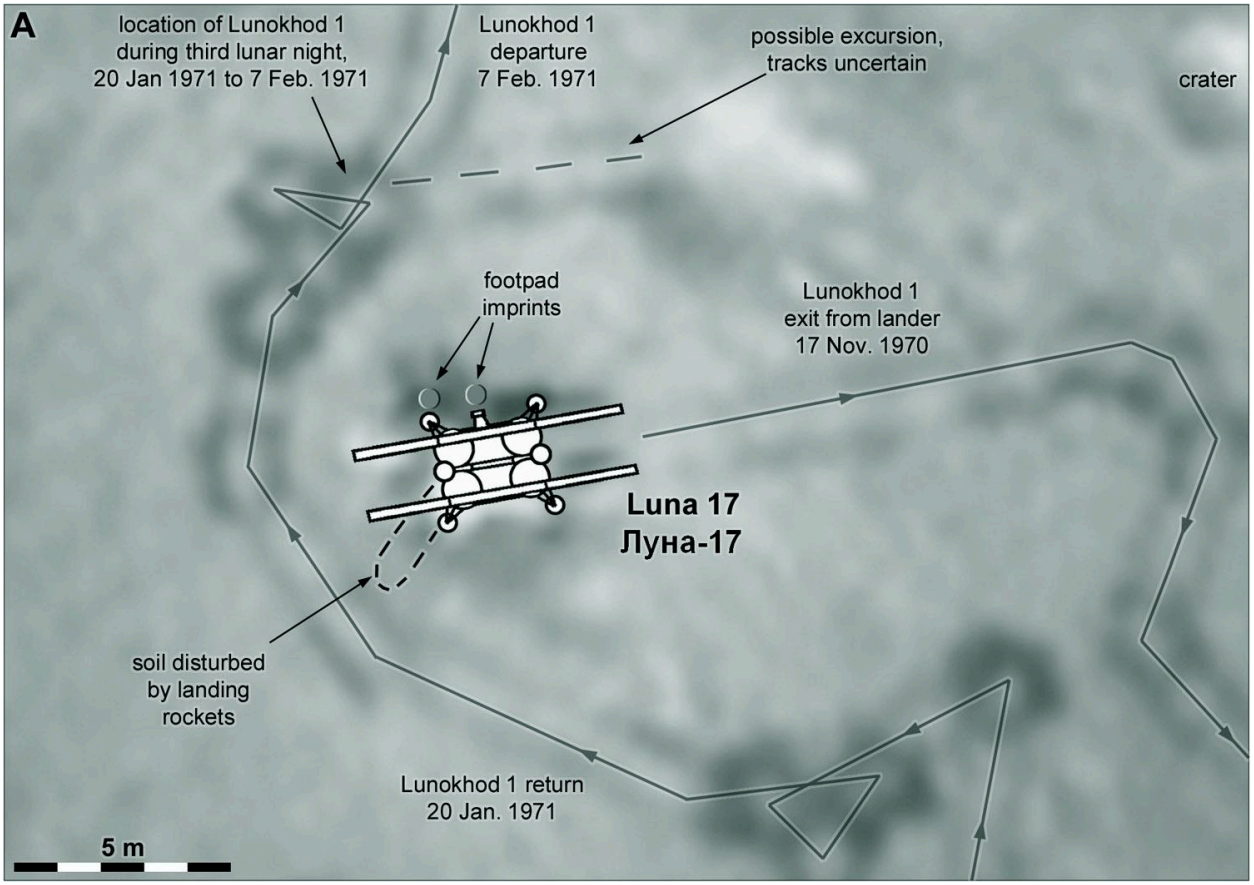
The 7th and last map of the Lunokhod 1 traverse. The rover entered the map at the middle of the bottom of the map, drove north and spent 3 lunar days moving among a group of craters. The distance driven on each lunar day became quite short in these last few days, around 100 m per lunar day, dropping to only a few tens of meters before the mission ended.

March 10, 2025 - #moon #luna17 #lunokhod1

The last day, the 11th, saw the rover stop just north of a crater called Leonid. Next we will look at the 'plan' areas noted on the maps and the actual landing site.

March 11, 2025 - #maps #moon #luna17 #lunokhod1

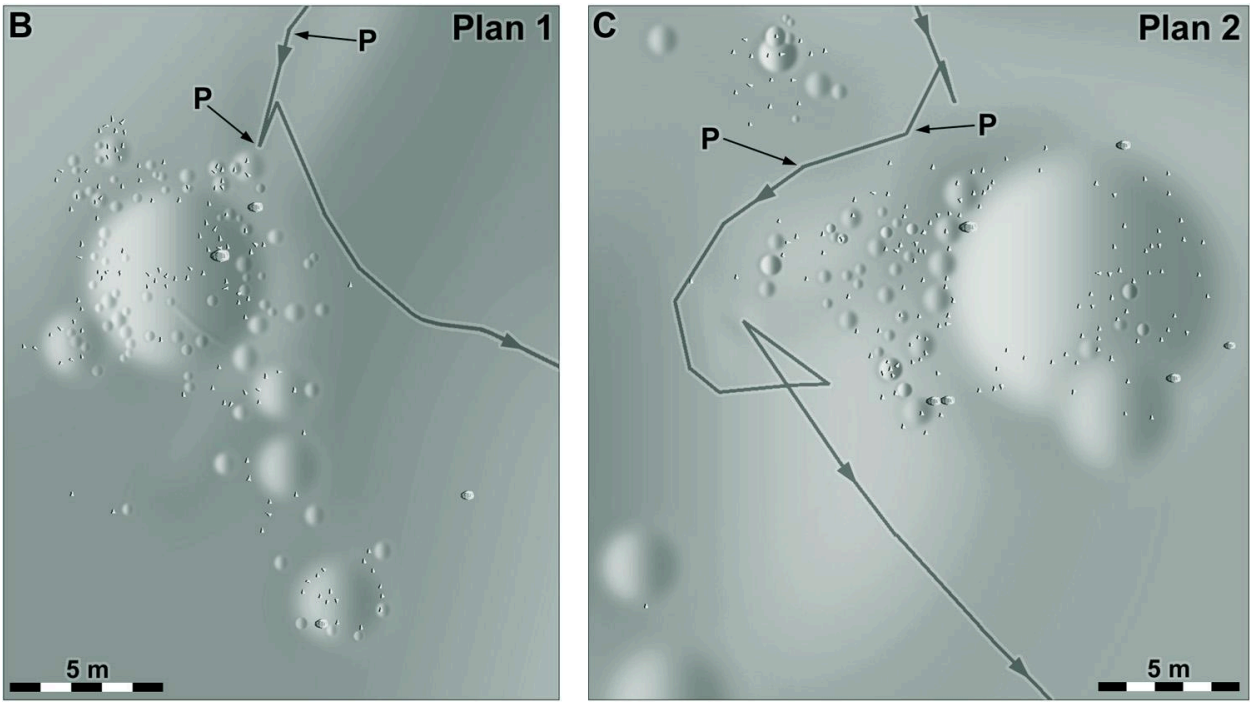
This is the immediate area of the Luna 17 landing site showing the paths of the rover around it. Lunokhod 1 departed on the east side, and after its excursion to the south it returned and drove around the lander, parking northwest of it. The dark rings are made by in-place turns, visible in LRO images. Some of the moves are to provide overlapping panoramas for stereo viewing. The footpad imprints and disturbed surface are visible in rover images.



A map of the area around Luna 17's landing site showing the motion of the rover around it. The lander is just left of centre. Lunokhod 1 drove off it to the right (east) and turned south. Two months later it returned and drove around the lander taking pictures of it. It parked for its third night just northwest (upper left) of he lander, and finally drove off to the north early on day 4.

March 12, 2025 - #maps #moon #luna17 #lunokhod1

The first map of the Lunokhod 1 traverse included two areas marked Plan 1 and Plan 2. These are the plans - maps, in other words. They were made using several panorama images to form stereoscopic pairs and the originals included contour lines as well as small crater outlines and rocks. I made a shaded relief interpretation of each plan. The plans appeared in Vinogradov, A. P., 1971. Peredvizhnaya laboratoriya na lune Lunokhod-1. Moscow: Nauka.



Two detailed plans showing rocks and craters based on Lunokhod 1 images. These maps are shaded relief interpretations of line-drawn Soviet originals.

March 12, 2025

While I was working on those shaded relief drawings I was comparing the panoramic images with the plans, and I discovered one or two places where the panorama just could not be made to fit the plan... until I noticed the panorama was printed in reverse (as if a negative had been flipped over). That got me into no end of trouble. Once seen it could not be un-seen and I suspected reversed images everywhere, leading to some very silly mistakes, mainly with Lunokhod 2.

March 13, 2025 - #maps #moon #luna17 #lunokhod1

I should have mentioned that the Vinogradov reference comes in two volumes. There was no corresponding publication for Lunokhod 2, alas.

Here are the remaining plans from Lunokhod 1 images, and a final map of the end of the traverse derived from LRO images of tracks and the old Soviet map.

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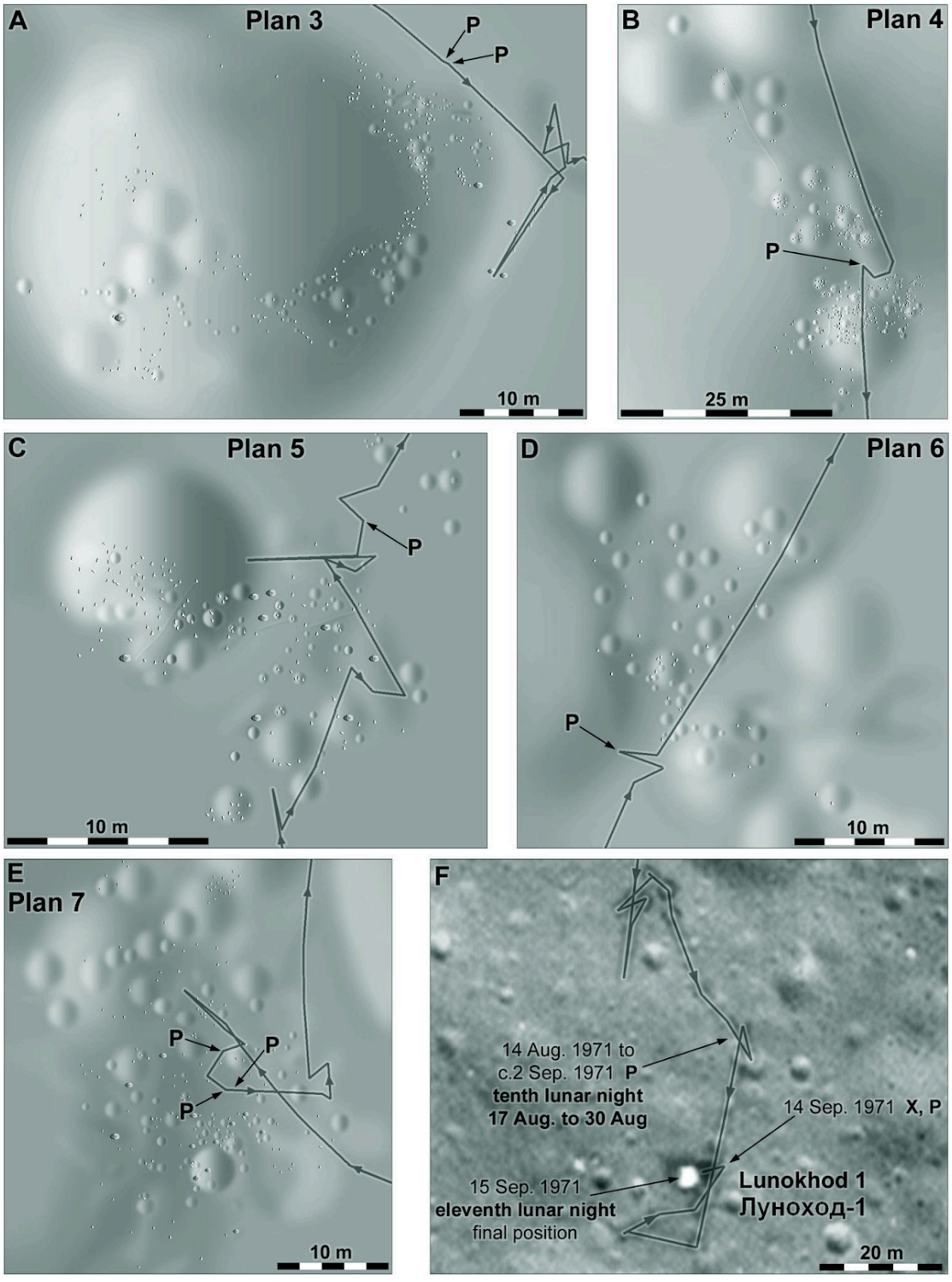


Six small maps of specific sites on the Lunokhod 1 traverse. The first five are shaded relief versions of the plans in a Soviet-era publication. The last (bottom right) map is the end of the traverse showing the final resting place of Lunokhod 1 and the drives leading up to it.

March 13, 2025

I will be looking at the current crop of landers after we conclude our look at Soviet/Russian missions (ending with Luna 25).

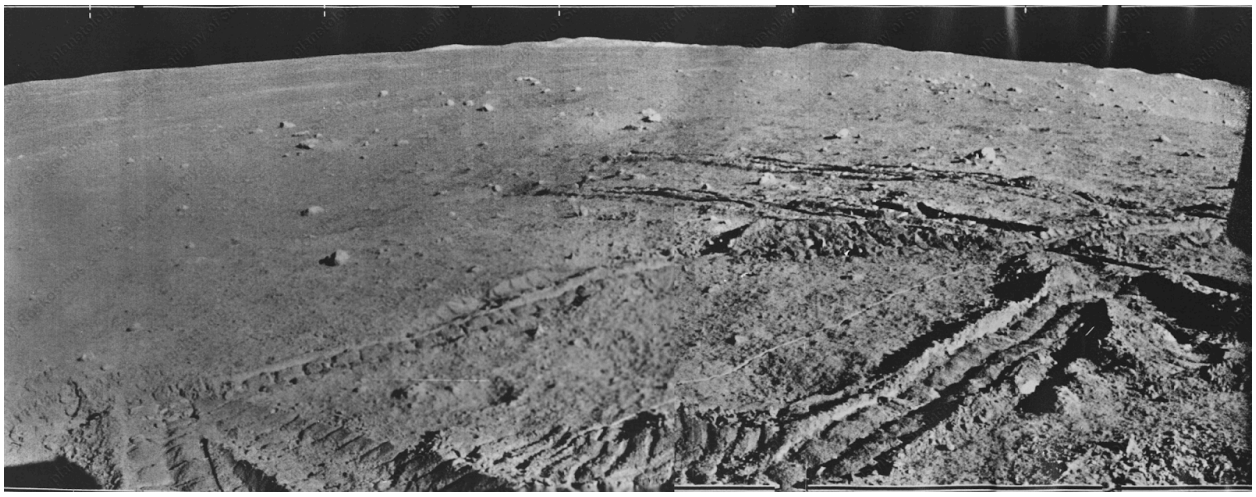
March 14, 2025 - #moon #luna17 #lunokhod1

This link goes to a Lunokhod 1 panoramic image taken on lunar day 9:

https://www.planetology.ru/panoramas/images/big/lunokhod1_c/L1_D09_S02_P04m.jpg

And here is part of it showing hills on the northern horizon (credit: Roscosmos and the Russian Academy of Sciences).

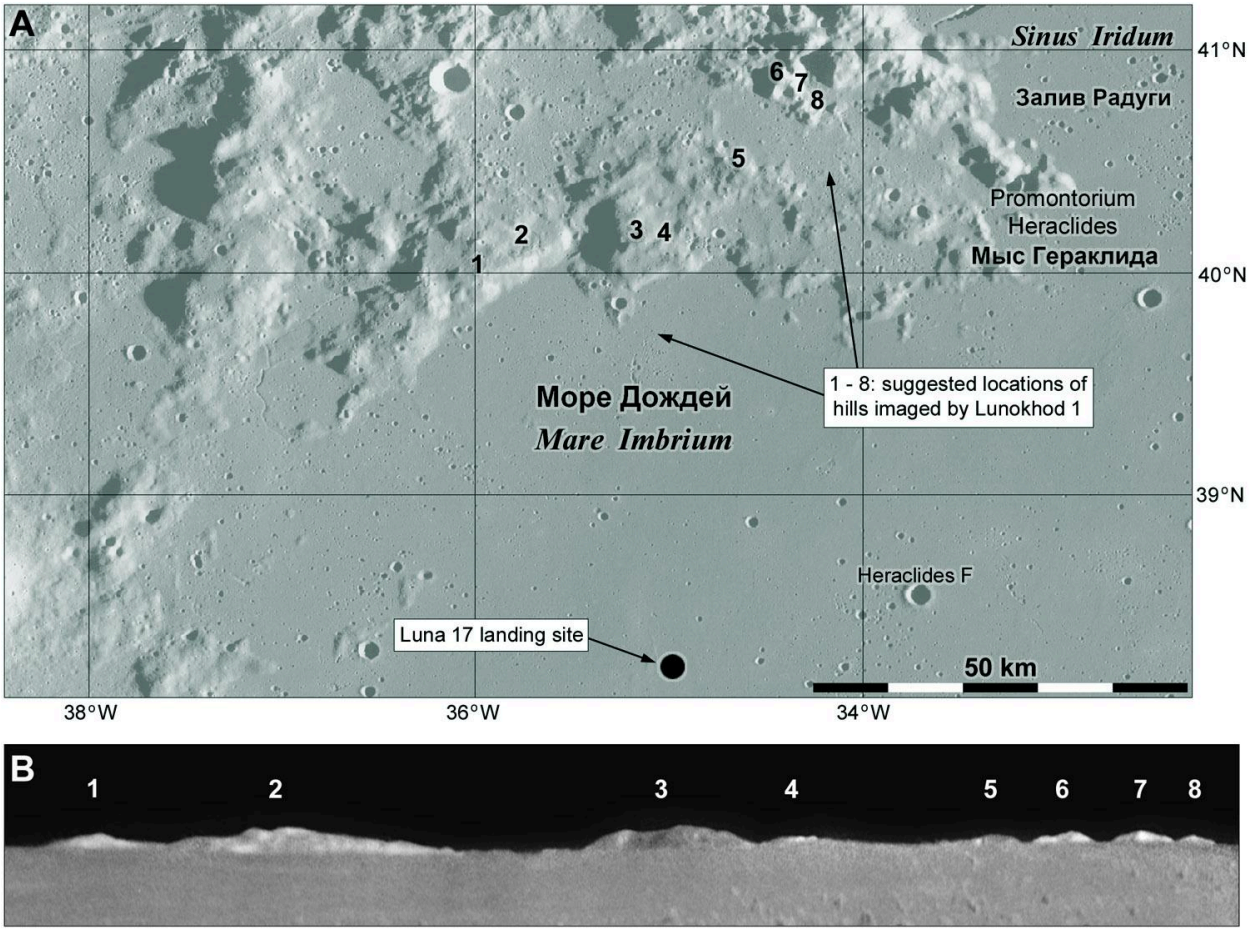
They are the only distant features visible at this site. Can we identify them? (Spoiler... yes!)



Part of a Lunokhod 1 panorama taken on lunar day 9 showing hills on the northern horizon.

March 14, 2025 - #maps #moon #luna17 #lunokhod1

Here I show the hills at the bottom - a composite of all available images of the hills to ensure maximum coverage and improved signal to noise. The map above shows the locations of the various peaks - the small eastern ones are less certain than the larger ones.

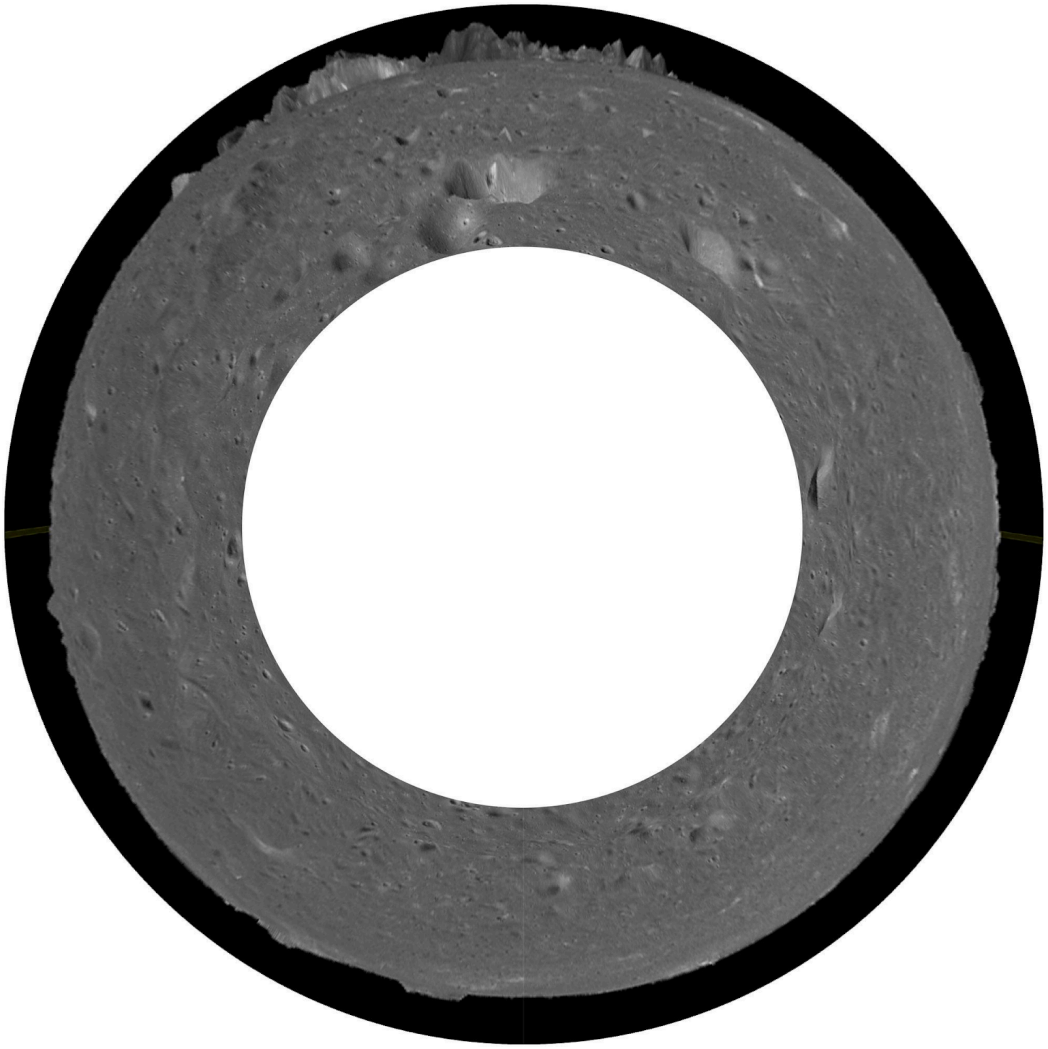


A view of the northern hills seen by Lunokhod 1 (bottom) and above it a map identifying the hills.

March 16, 2025 - #moon #luna17 #lunokhod1

The Moon has been keeping me busy lately, but I'm back on the job. That view of the northern horizon showing distant hills can be replicated using synthetic panoramas made in Quickmap: (https://quickmap.lroc.asu.edu).

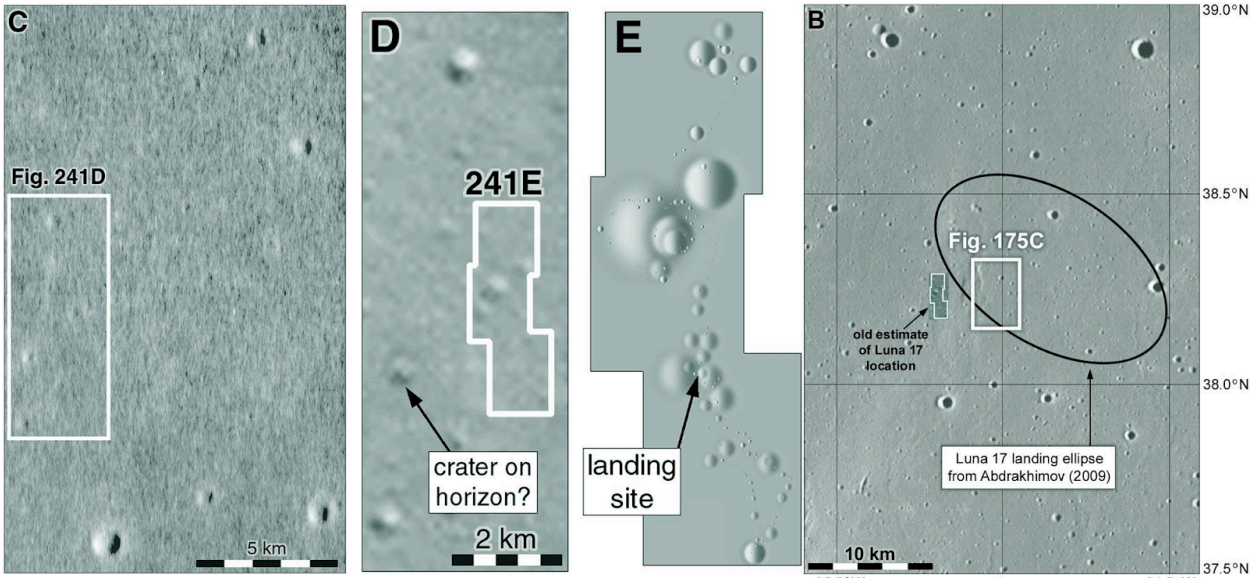
Here is a panorama made at the Luna 17 location but at an elevation of several hundred meters, so it looks a bit further over the horizon. There are hills in other directions not seen by Lunokhod 1.



A synthetic panorama made using Quickmap. The location is the Luna 17 landing site but the elevation is several hundred meters p so the view looks further over the horizon. I am finding elevation tricky to control in Quickmap! This shows the northern hills and a few other hills and crater rims in other directions, but no full panorama can be made from the Lunokhod 1 images.

March 17, 2025 - #maps #moon #luna17 #lunokhod1

There is one other thing I want to say about Lunokhod 1. I will start by combining two posts from earlier in this sequence. This image shows 3 panels at left illustrating my old guess about where Luna 17 landed (best image at the time, from Apollo 15; a map of the traverse area showing craters on the old Soviet map, and between them, where I thought that map fitted on the image. At right is a context map for my later maps, with the old outline added.



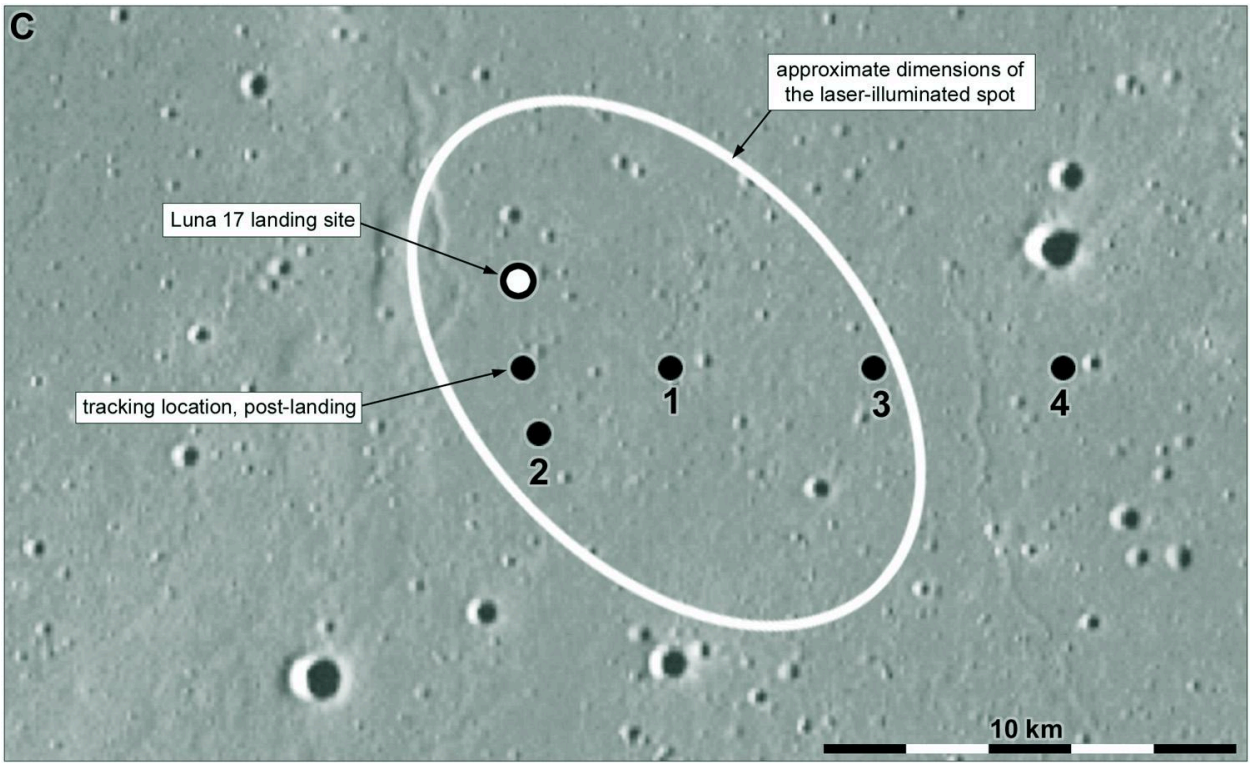
This map combines two earlier posts. At left is the best pre-LRO image of the Luna 17 area, from Apollo 15. In the middle is my relief version of the old Soviet map showing craters in the Lunokhod 1 traverse area. Between them is my estimate of where they fit together. At right is my modern context map showing the Luna 17 landing ellipse and a box locating my later 'zoom in' set of maps. I have added the old location. I was about 6 km too far west.

March 17, 2025 - #moon #luna17 #lunokhod1

The significant thing to take from this is that I was about 6 km too far west. I chose that spot because it was the only place where there seemed to be a pair of craters matching the largest two in my relief map. As we have seen, the largest one doesn't really exist so I was never going to get it right. In fact, even the biggest crater (Borya) in the traverse area is almost invisible in the old image. This became a problem beyond just me being wrong...

March 18, 2025 - #maps #moon #luna17 #lunokhod1

To know where Lunokhod 1 was before LRO revealed it, the attempt at matching a map to images is one approach. But there was another - laser reflections. Lunokhod 1 carried a reflector supplied by France. The Vinogradov reference (Vol. 2) summarizes contemporary results, shown here. The ellipse is the spread-out footprint of a laser shot from Earth (footprints are much smaller now). laser shots centred at 1 and 2 gave reflections, but weakly at 3, not at 4.



A map of the Lunokhod 1 area showing a roughly 10 by 15 km ellipse, the area covered by a laser beam transmitted from Earth. A reflector on the old rover reflected photons back to Earth. Several points are marked - the Luna 17 landing site and the estimated location from tracking, plus 4 numbered spots. Laser shots centred at points 1 and 2 returned photons. Shots centred at 3 did weakly, and at 4 hardly at all. This helps narrow the location of the rover somewhat.

March 18, 2025 - #moon #luna17 #lunokhod1

My location for Luna 17 was too far west but was not ruled out by the laser data. Here is my LPSC abstract on it from 2005:

https://www.lpi.usra.edu/meetings/lpsc2005/pdf/1194.pdf

I was contacted by the team trying to get new detections from Lunokhod 1:

https://arxiv.org/pdf/1009.5720

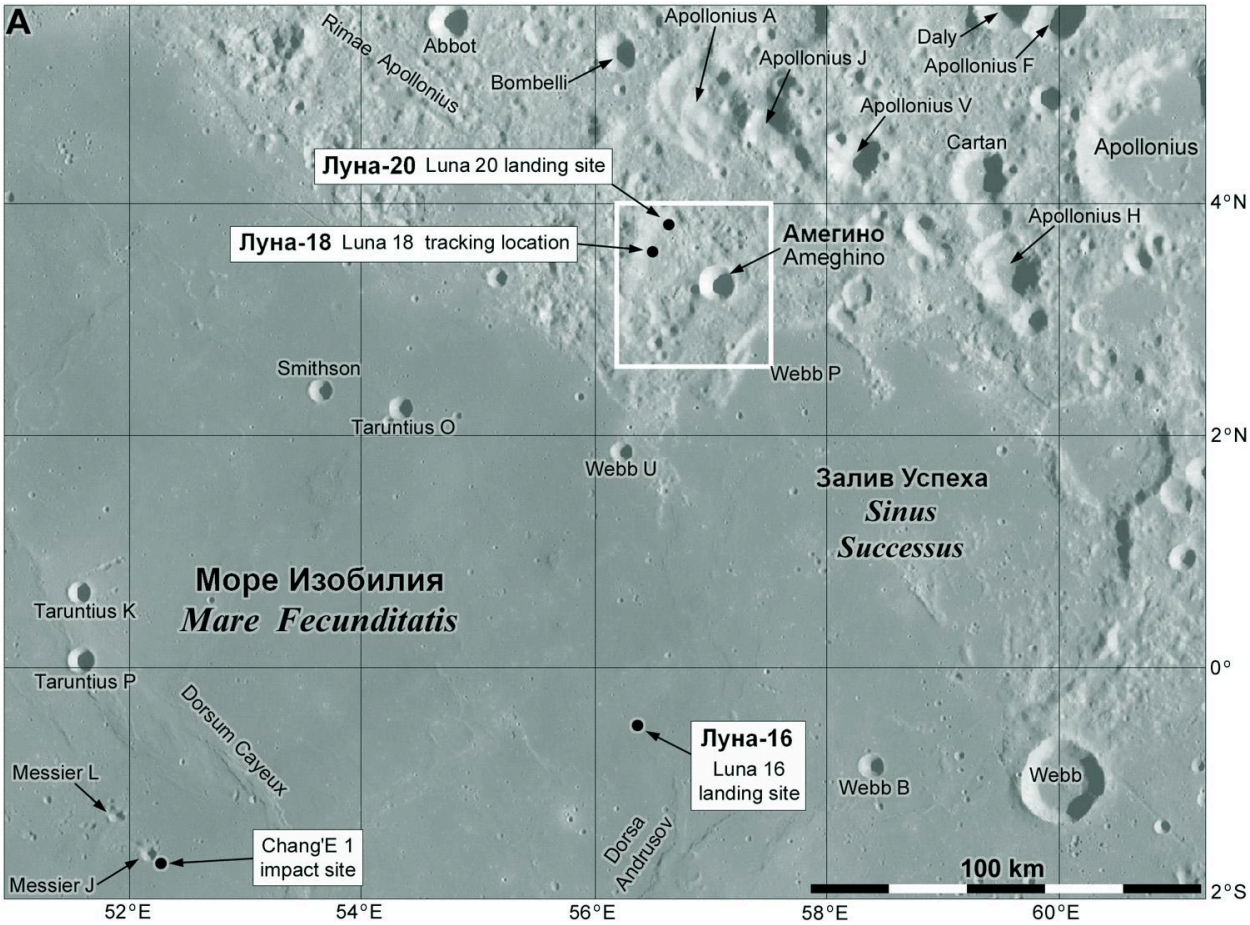
With a small footprint and a very narrow range gate (see the second link) the uncertainty made the reflector very hard to detect, and my error wasted some of their time. Only when LRO found the rover did they succeed.

March 19, 2025 - #moon #luna18

Moving on to Luna 18 now... this was another sample return mission like Luna 16. The area accessible to these sampling missions was very limited and within it was Mare Fecunditatis, sampled by Luna 16, and a highland region north of it which was another obvious target. NSSDCA has a description of the mission here:

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1971-073A

Things were going wrong during the flight and Luna 18 failed at some point during the landing attempt. Can we find it?

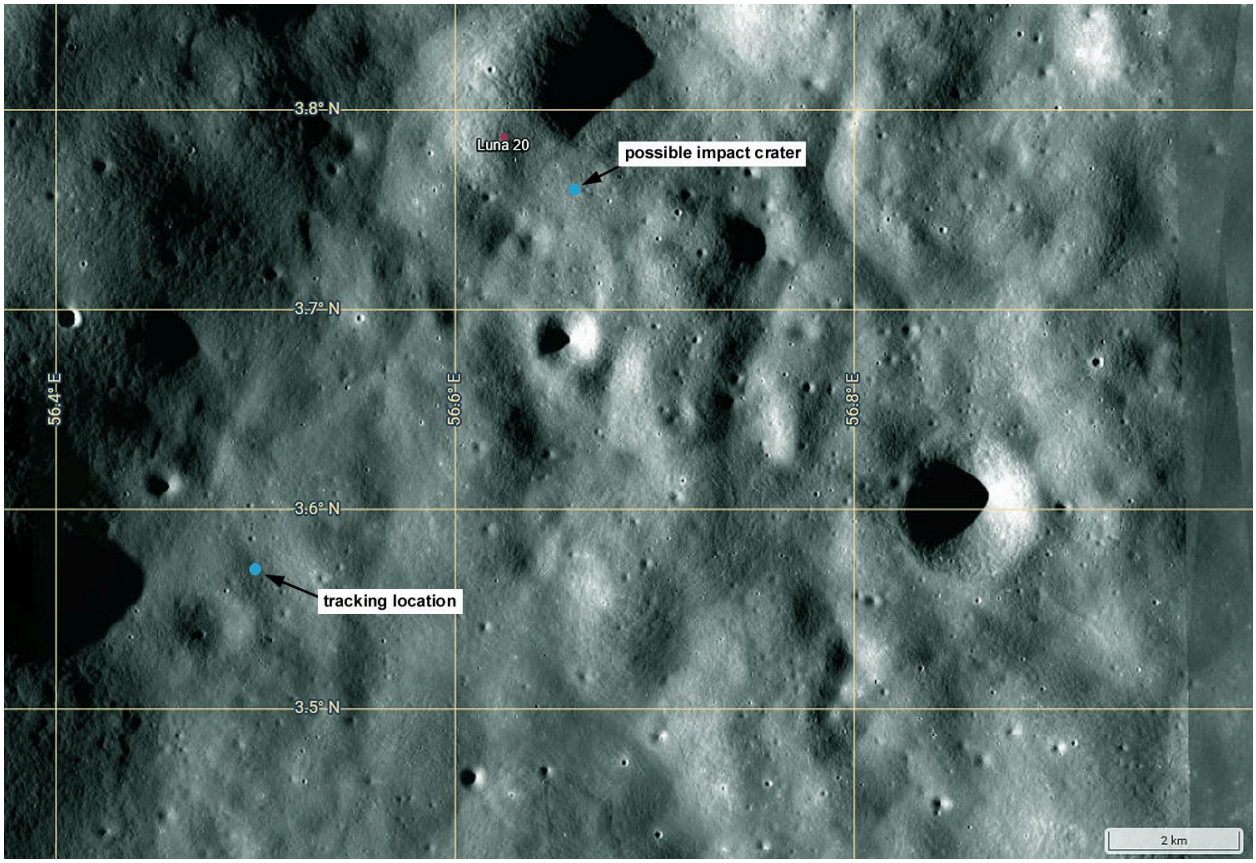


A map of the region around the Luna 18 landing target. Luna 16 landed in smooth dark plains in the lower middle part of the map. Luna 20 would land later in the rugged highlands in the upper middle part of the map. Luna 18 was targeted for the same basic area as Luna 20 but it crashed.

March 20, 2025 - #maps #moon #luna18

The NSSDCA link yesterday says the Luna 18 impact was tracked to c. 3.57 N, 56.50 E, and that LRO shows a crater which may be the impact site at 3.76 N, 56.66 E.

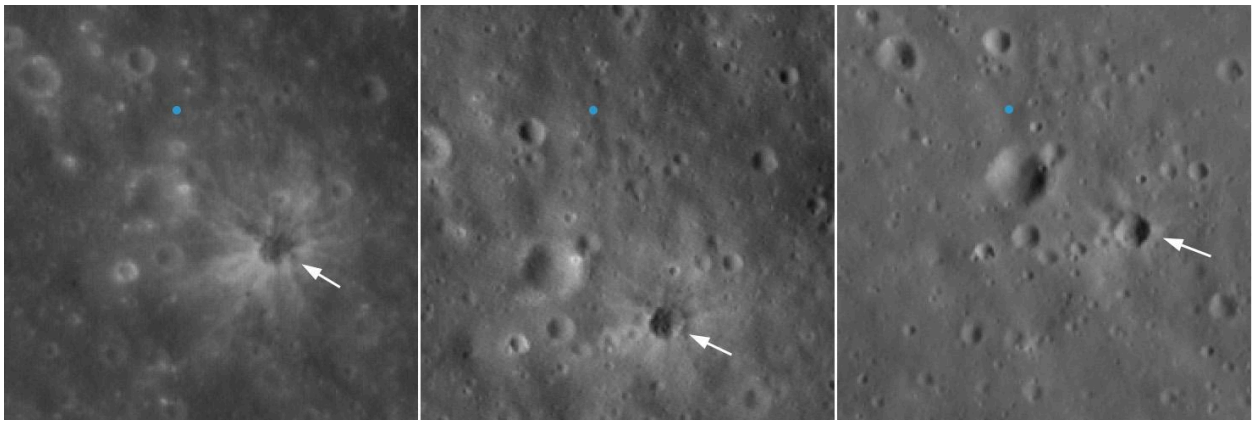
My map, from Quickmap, shows those locations and Luna 20's landing site. I had not seen the impact crater suggestion until right now when I looked it up for you, dear reader. I think it's a bit too far from the tracking position but not impossible. Let's take a closer look... #maps #moon #luna18



The Luna 18 impact area in a map from Quickmap, with an LRO base image and a lat-long grid. Luna 20's landing site is near the top of the map. About 6 km southwest of it, in the lower left corner of the map, is the point suggested for Luna 18 by tracking at the time of the mission. 1200 meters SE of Luna 20 is a fresh-looking impact crater which some unknown person has suggested might be the Luna 18 impact site.

March 20, 2025 - #moon #luna18

The crater can't be seen in that last map but here I zoom in on it. The blue dot is the indicated latitude and longitude. Note how it seems to move relative to the craters... but this is deceptive. It's the craters which are moving, the point is fixed. Each image (from 3 separate NAC layers in Quickmap) is registered to the coordinate grid differently, illustrating how uncertain coordinates are in this or any other map. But is it the right crater?



Three images of the potential impact crater made by Luna 18. A blue dot shows the coordinates given in the linked source. The craters seem to move between images because they are not perfectly registered to the coordinate grid. A crater with bright rays is indicated in each image by an arrow.

March 20, 2025 - #moon #luna18

First, the crater is not at the indicated coordinates in any image. The coordinates were probably assigned early in the LRO mission and have not been updated as registration has improved. The crater is about 20 m across. Ranger craters were 10 m across, Apollo Saturn upper stage craters were 40 m across. This might be OK for something coming in fast like those things, but it's too big for something which was braking for a landing So what happened to Luna 18?

March 20, 2025 - #moon #luna18

There are conflicting stories about Luna 18 (landed on a slope and fell over, ran out of fuel as it descended) but they all seem to agree it was already travelling quite slowly (by orbital standards) as it came in for a landing. Any crater should be small, and it might have landed nearly intact and not made much of a crater, just broken up.

I don't think this can be the right feature, but I have searched for it and not found anything. Another mystery on the Moon!

March 21, 2025 - #moon #luna19

Next in line is Luna 19. This was an orbiter using the Lunokhod landing platform adapted for orbital observations. We don't know a lot about it. Here is the NSSDCA description:

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1971-082A

Don Mitchell has some images (near bottom of his page):

http://mentallandscape.com/C_CatalogMoon.htm

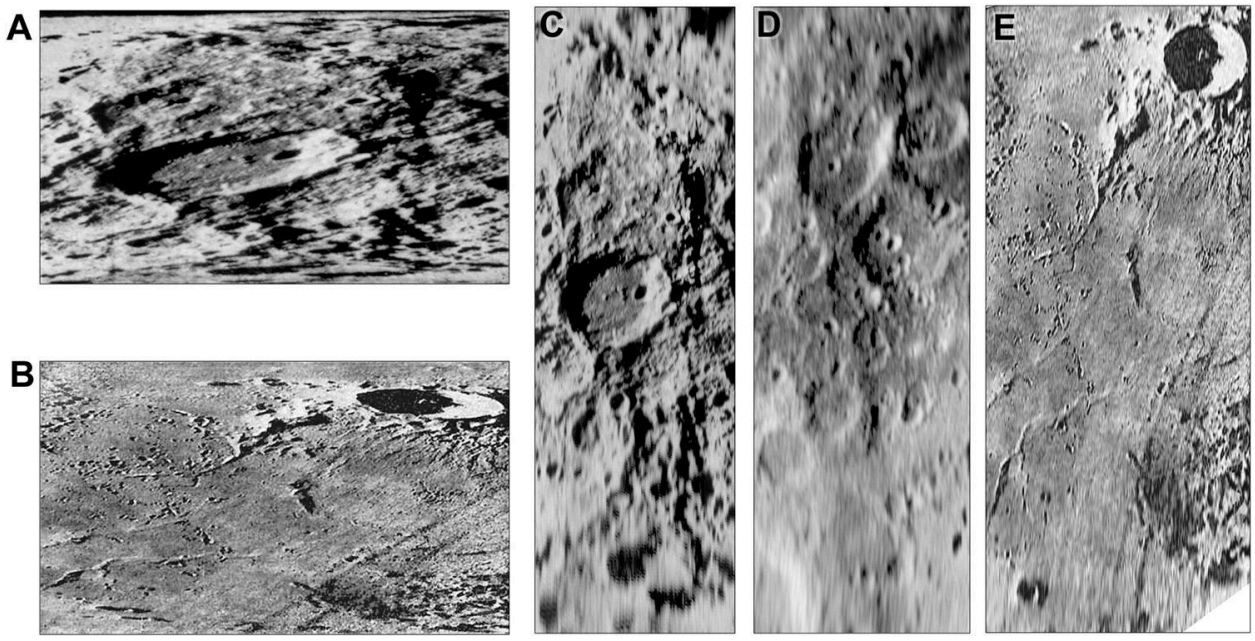
The most reported results are from a camera system, but there were also radar reflectivity (I think this means bistatic radar) and occultation observations probing dusty plasma near the surface.

March 21, 2025

I looked at all this stuff over 20 years ago for my old Moon book, but now that I am summarizing things here and preparing my new Magnum Opus I am finding new things to update my maps. Tomorrow we can look at what is going on with Luna 19 in more detail.

March 22, 2025 - #moon #luna19

Let's start with the images taken by Luna 19. The NSSDCA text mentions 2 TV cameras. Don Mitchell calls them scanners (which is correct, though there are hints both systems might have been used). The scan line ran from horizon to horizon and orbital motion moved the scan line along the track. Oddly some images seem to have scan lines diagonal to the ground track. There's a lot we don't know. Only 5 images have ever been released... here are 3 of them.



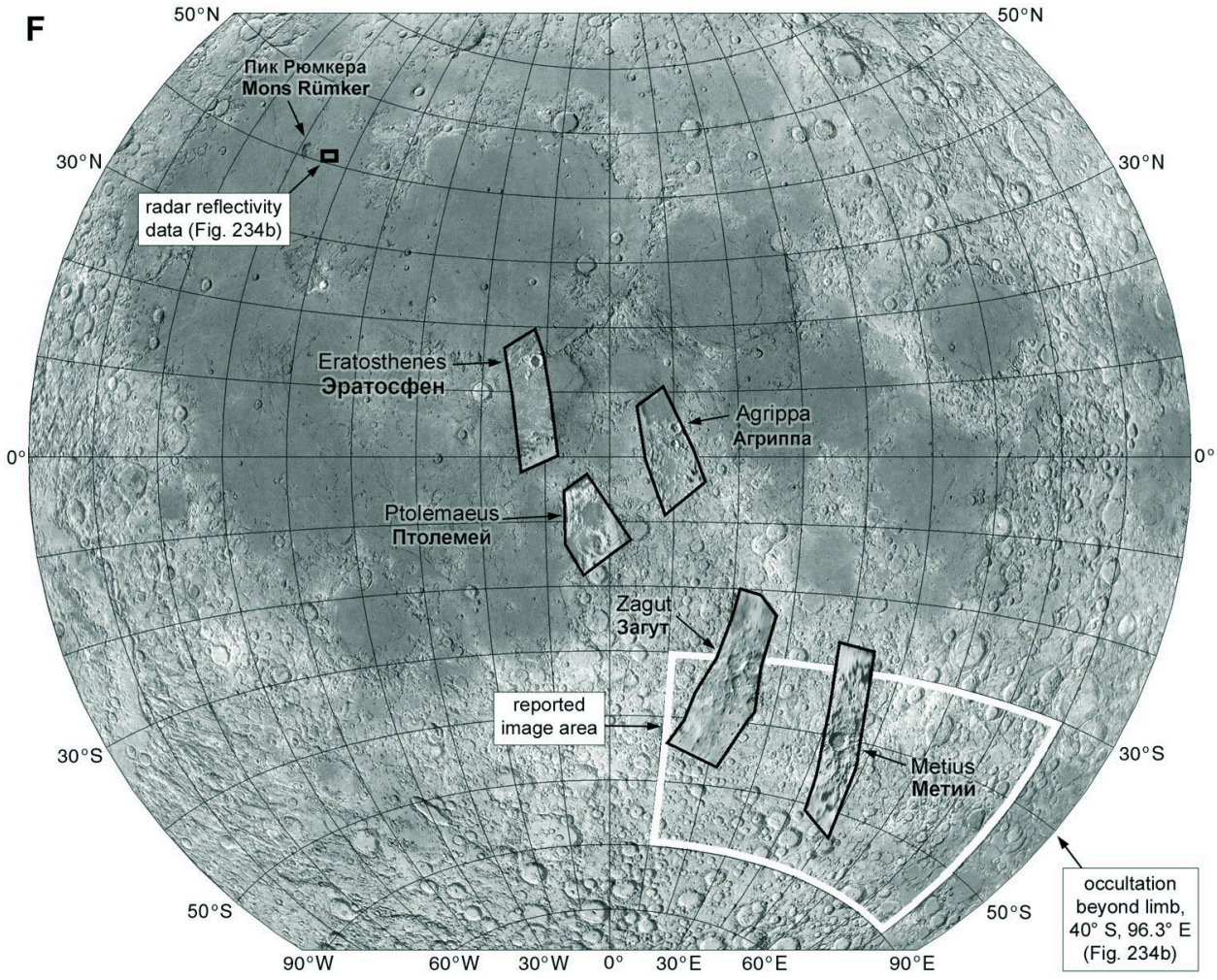
Three images from Luna 19. At left are two images in their original geometry, with the horizon at or just beyond the top and bottom. At right are those two images and a third example projected into a more map-like geometry, removing the extreme foreshortening near the horizon.

March 22, 2025 - #moon #luna19

Presumably the originals were higher resolution, but how much higher? If really good images were obtained, we would have seen them. The other 2 images are only seen in very low quality prints. There seem to be no publications on the results, leading me to think they were engineering tests of cameras intended for other destinations (Mars 4 and 5 carried modified scanners later). These images were essentially useless for science or landing site selection.

March 22, 2025 - #maps #moon #luna19

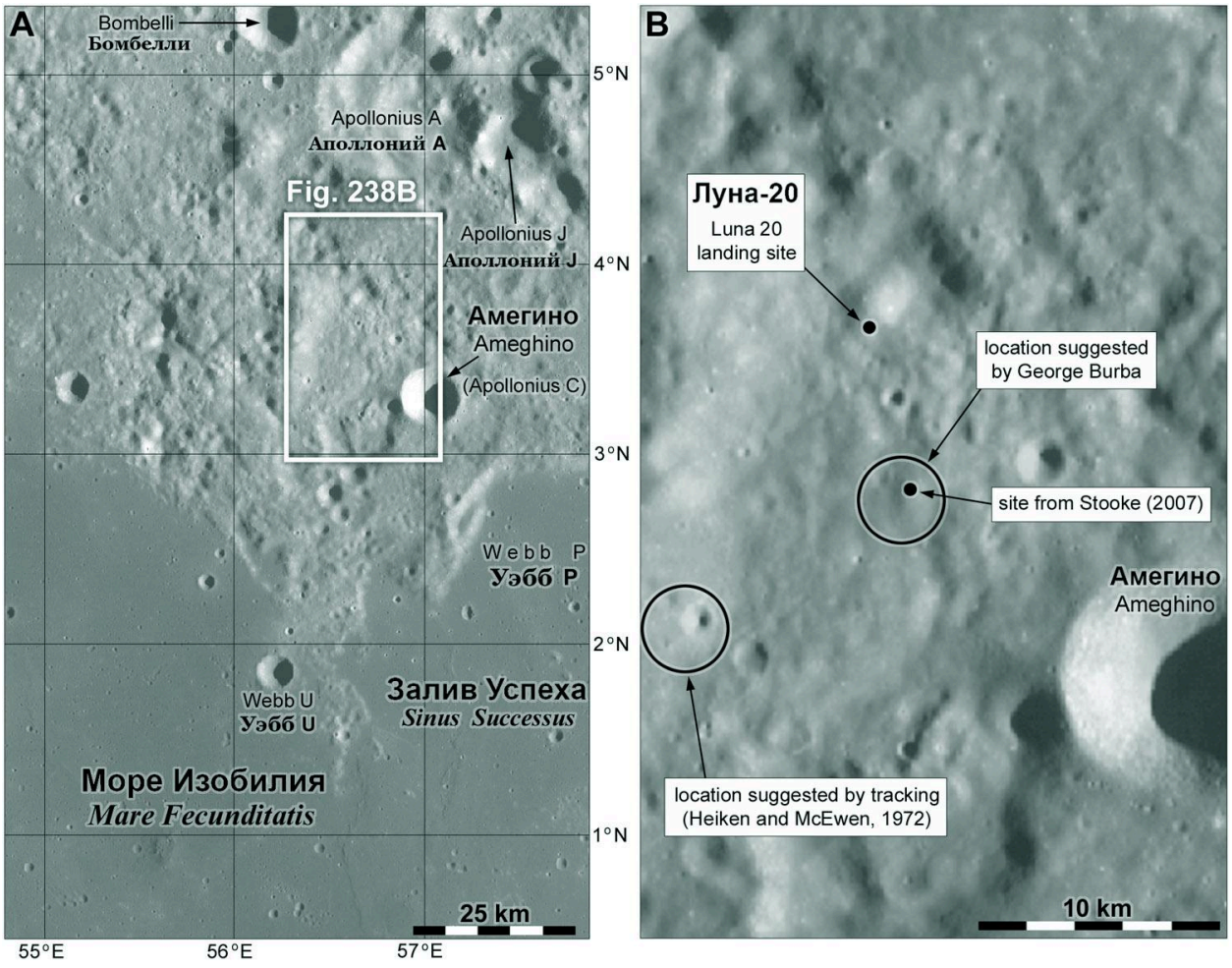
This map shows the areas covered by Luna 19 images. Some reports said they covered an area marked as a white box, but there are others outside it. Luna 19 also made radar reflectivity measurements (upper left) and used a radio occultation to probe plasma above the surface (text at lower right). Those results were published. The radar experiment used the radar altimeter but there's no sign of any actual altimetry being done. A confusing situation!



A map of the Earth-facing side of the Moon (omitting the poles), showing the locations of the five known images taken by Luna 19. Two other locations are indicated: a radar reflectivity experiment at top left and a radio probe of plasma above the surface at lower right.

March 23, 2025 - #maps #moon #luna20

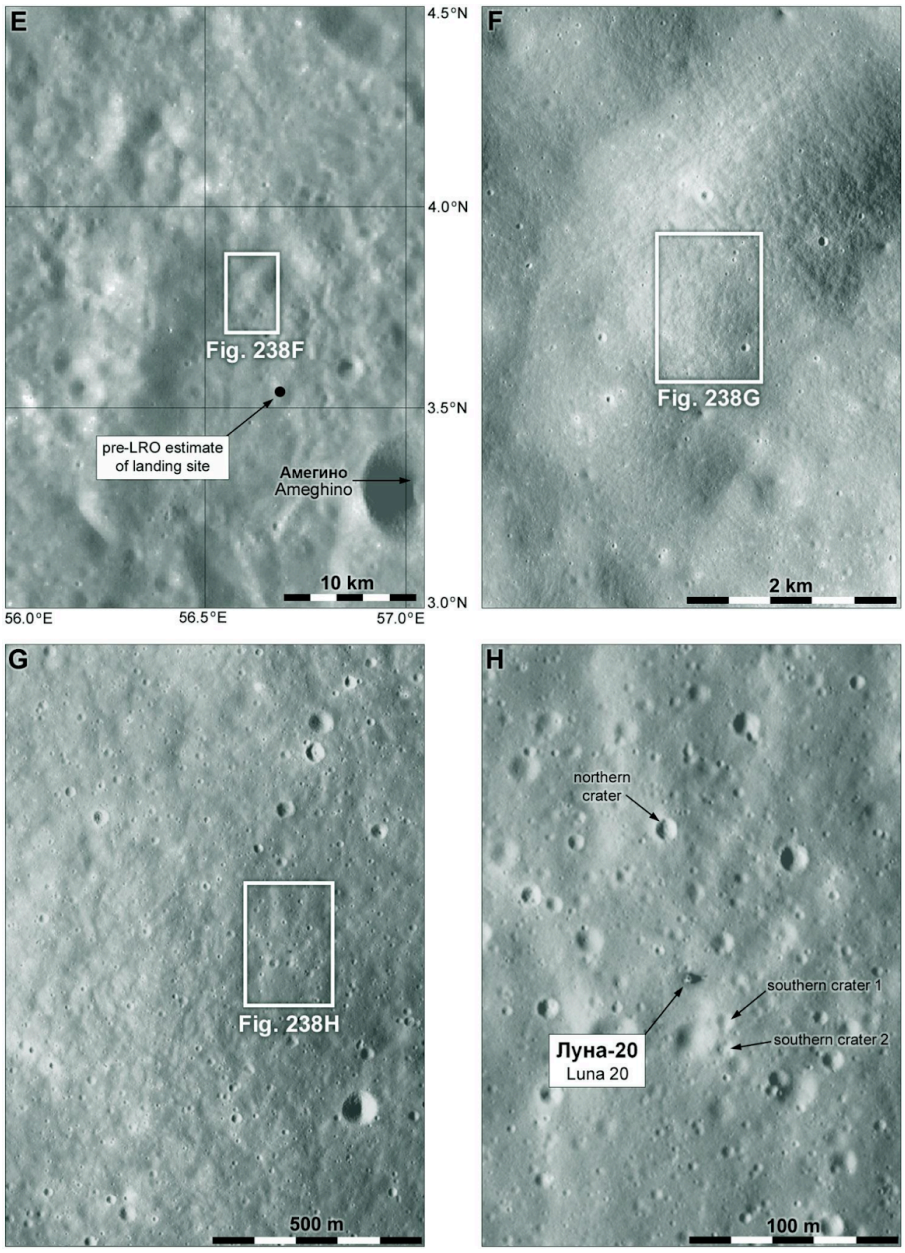
Luna 20 was the next sample return mission, sent to the same location as Luna 18, and this time it was successful. My map shows the region, and a closeup of a broad depression showing a few guesses about where it landed. This was a candidate Apollo 17 landing site as well, and it was specifically dropped because it was an area that a Soviet lander might sample. My old book had a mistaken guess about the site and we will soon see how that happened.



Two maps showing the Luna 20 landing site. At left is a regional view showing a flat-floored depression in the highlands between Mare Crisium and Mare Fecunditatis. At right is a closeup of the area showing several suggestions about where the lander might be. LRO shows the real location near the north end of the depression, about 15 km northeast of the tracking location.

March 24, 2025 - #maps #moon#luna20

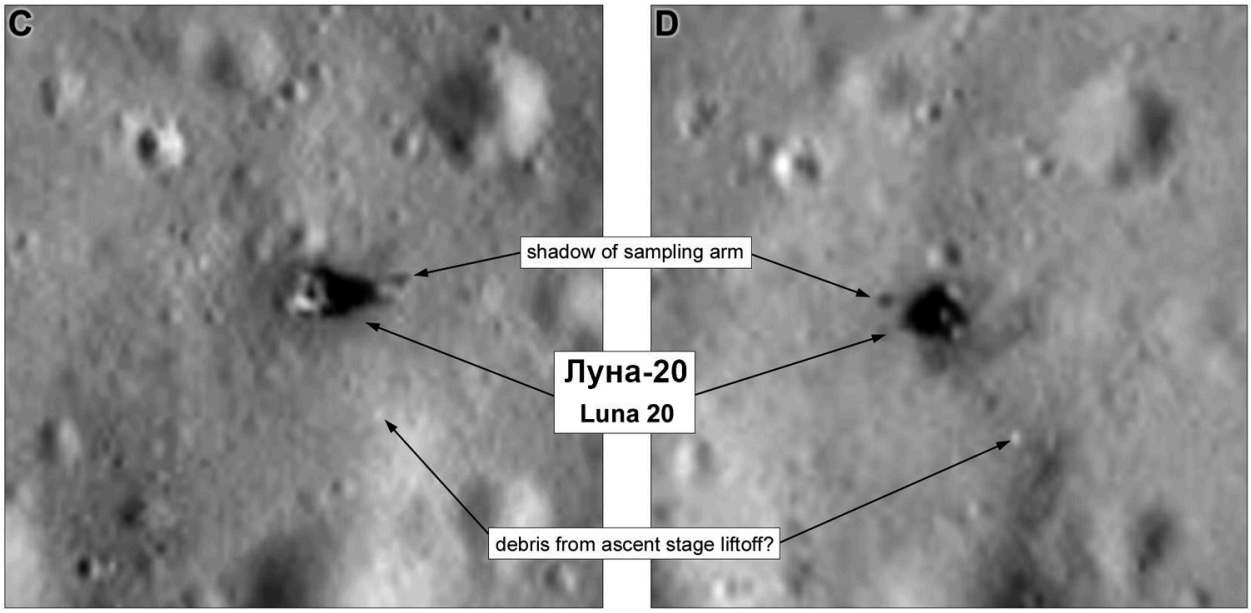
This set of maps zoom in to the Luna 20 landing site. In the last image an object is labelled 'Luna 20'. How do we know this is indeed the lander and not just some rock? First, it's about the right size and shape. But we can do better. Zooming further in (next post) we can see the object more clearly and especially its shadow, which is very distinctive.



Four maps zooming in o the Luna 20 landing site. The last image at lower right shows the lander itself sitting on the surface. A few craters are noted which we will see later in a different perspective.

March 24, 2025 - #moon #luna20

These are two LRO images of Luna 20 with opposite illumination - afternoon on the left, morning on the right. The shadows are both accompanied by a small shadow cast by some object, and it's clearly held high enough for the shadow to appear on opposite sides of the lander. It's believed to the a structure on the end of the sampling arm, which was lifted up high to deliver the sample to the return capsule.



Two pictures of Luna 20 on the lunar surface taken by LRO's fabulous narrow-angle camera. A small shadow is pointed out - apparently the sampling arm which was raised to deliver the sample to he return capsule. A small bright spot may be a fragment of thermal blanket or other material thrown off by he blast of the ascent stage rocket. Similar things are seen at other sites where a return vehicle has taken off.

March 25, 2025 - #moon #luna20

Luna 20 was the only Soviet sample return lander which imaged the surface (Luna 16 did as well, but long after sunset). So we could compare those pictures with LRO images to locate Luna 20. I tried that in my old Moon book but had the orientation wrong and tried to match features in the wrong place. Such is the malleability of the human mind that I made it work anyway (and you thought AI was dumb!) Let's have a look at the pictures. These fragments are all I have seen.

Several fragments of a panorama made by Luna 20. We don't know if a whole panorama was made, but this is all I have ever seen. These fragments come from scans made at MIIGAiK in Moscow, and sections from Don Mitchell and Ted Stryk.

March 25, 2025 - #moon #luna20

This needs some explaining. First, fragments come from scans made at MIIGAiK in Moscow, and from Don Mitchell and Ted Stryk. Ted has done great work over many years rescuing obscure planetary data - see his work here:

https://bsky.app/profile/tedstryk.bsky.social

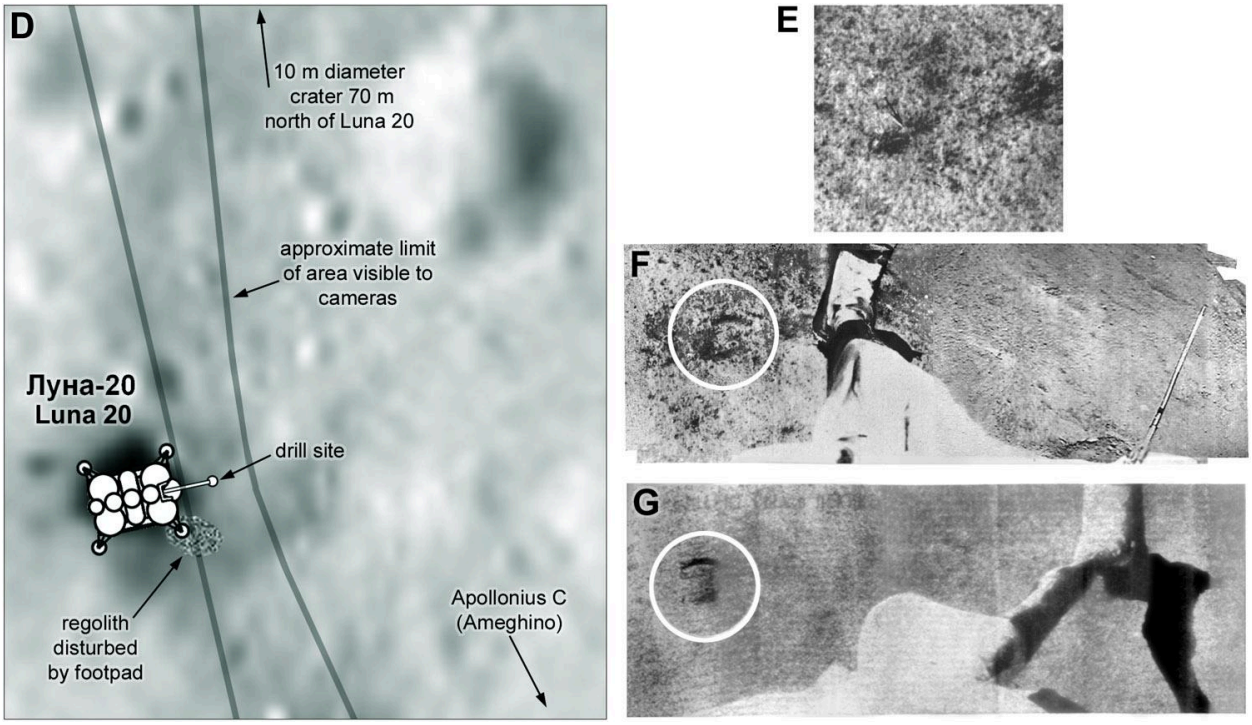
There were 2 cameras, one each side of the drill. Each scanned from the horizon to the foreground. Put them together and you get a full 180 panorama with the foreground in stereo. In the middle is the drill on its arm.

March 25, 2025 - #moon #luna20

We don't know if the missing parts were imaged, though I expect they were. Ted has assembled these fragments differently, I like to think somewhat artistically, to make a view without gaps, but I think this is more accurate. At far left is a bit of the horizon to the north with a crater ('northern crater' in yesterday's post). At far right is a more hilly horizon. In my old book I thought this was to the east but it's not, it is south of the lander.

March 26, 2025 - #moon #Luna20

This map shows the approximate area near the lander covered by the camera (not just the small image sections in the panorama as posted). With it are three images of the sampling area. The top image shows the surface before sampling. The other two images (taken by the two cameras, hence the different geometry) show the arm with the drill and a surface marking showing where the sample was collected (circled).



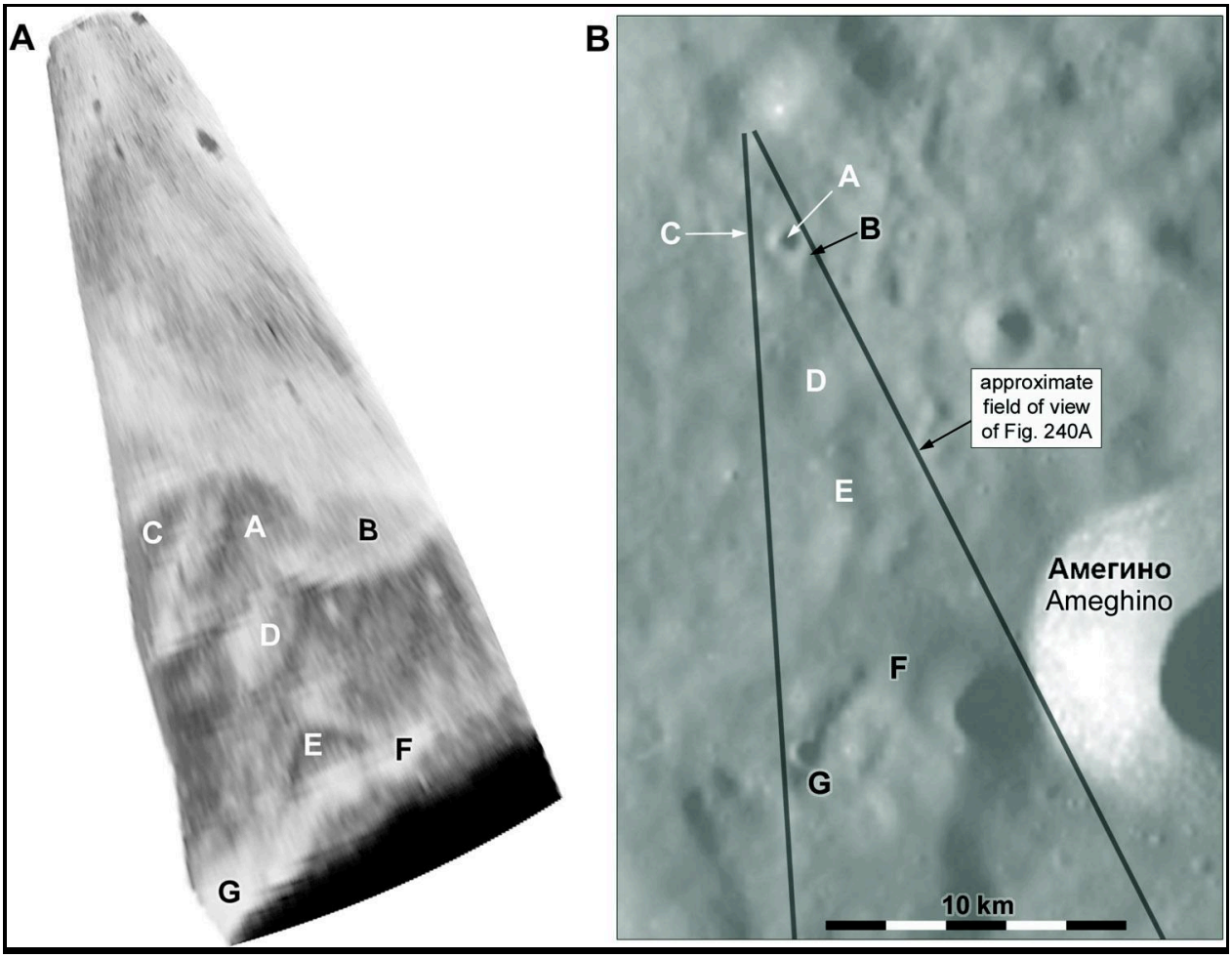
A map of the Luna 20 site showing the area potentially scanned by the camera (it should probably widen out more away from the lander), and three images showing the sampling area before contact (top) and after the sample had been collected. The sampling point is circled.

March 26, 2025 - #moon #luna20

There is so much that we don't know about the images - was there ever a full panorama, for instance, or could we make a topographic map of the sampling area from stereoscopic images?. But another thing suggested by these different views is the possibility that enough images might have been taken during the sampling process to make a brief animation. If only the raw data could be retrieved and made public! My image processing chums would have a great time.

March 27, 2025 - #moon #luna20

One last thing about Luna 20. Where are the hills seen in the distance at the right end of the panorama? In my old book I thought they were to the east of the (erroneous) lander position, north of the crater Ameghino. Now I understand the geometry better and we know where the lander is, I see the hills are south of the lander, west of Ameghino. Here is a very rough schematic projection of the end of the panorama and a map showing my interpretation of the scene.



On the left of this image is a rough perspective projection of the right-hand end of the Luna 20 panorama. On the right is a map of the area showing the approximate area covered by the image with a few features matched by letters.

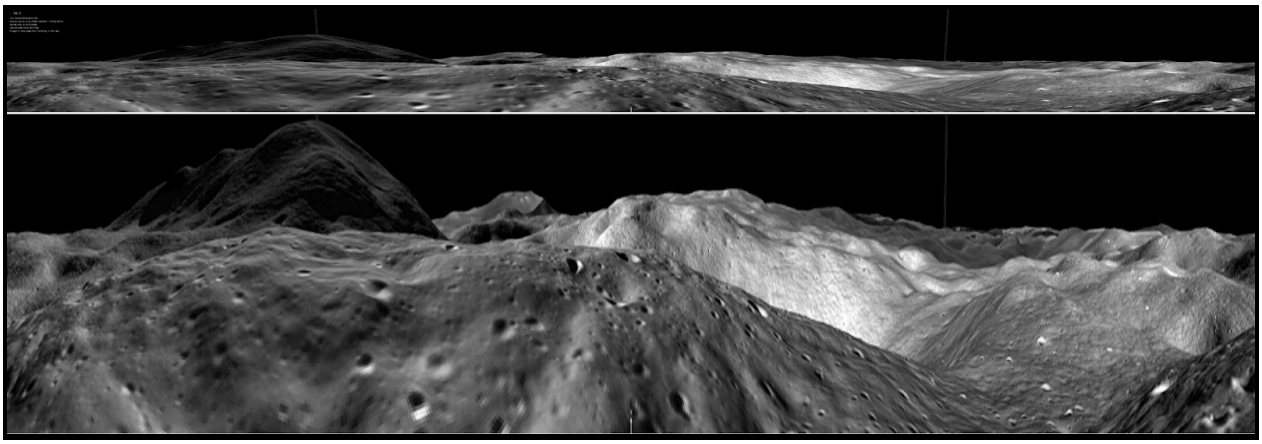
March 27, 2025 - #moon #luna20

Good grief! It's just occurred to me that I can make a synthetic panorama of this scene in Quickmap. I'll do it for tomorrow... why didn't I think of that before?

March 28, 2025 - #moon #luna20

Public Service Announcement. Never allow yourself to make promises on the internet unless you are absolutely certain that what you are proposing is a good idea.

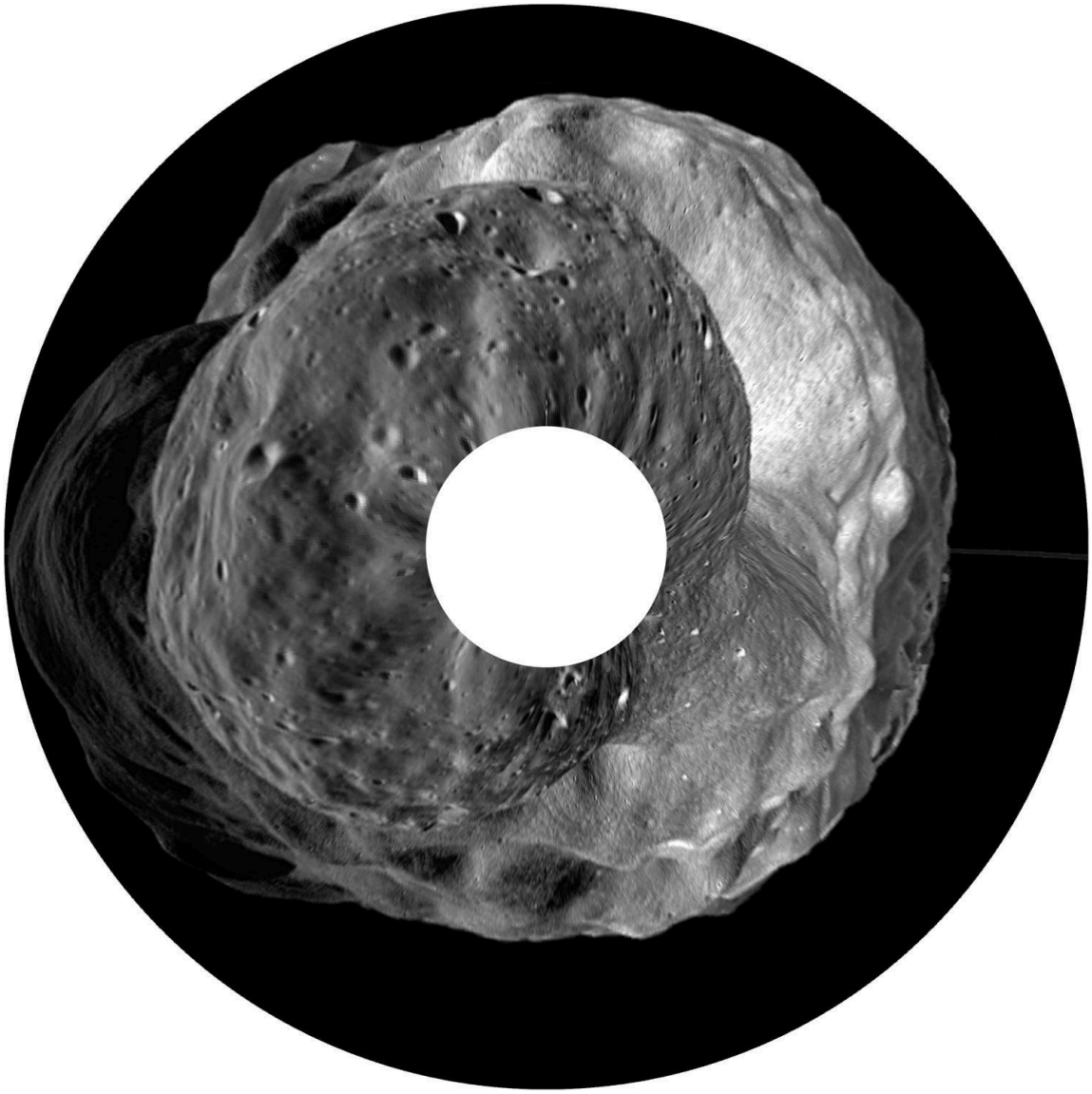
Yesterday I rashly said I would make a synthetic panorama for the Luna 20 site, assuming it would help me establish what the lander camera saw. Well, here is the result and it doesn't help much at all. The panorama is the top image, and a 4x vertical stretch is the bottom image. North is in the middle, south at each end.



A synthetic 360 panorama for the Luna 20 landing site, made in Quickmap. At the top is the original panorama, and below it is a version with a 4x vertical stretch. It's a very hilly landscape. North is in the middle.

March 28, 2025 - #moon #luna20

Here is a circular version of the same synthetic panorama. The lighting is not the same, which doesn't help. The view is from some elevation, it doesn't go all the way to the surface. This cuts off enough of the lander foreground that the 'northern crater' seen well in the panorama is lost in the blank middle bit. I have not yet learned how to avoid that happening. The rim of Ameghino is not as obvious as I expected. I think I will move on to Luna 21...

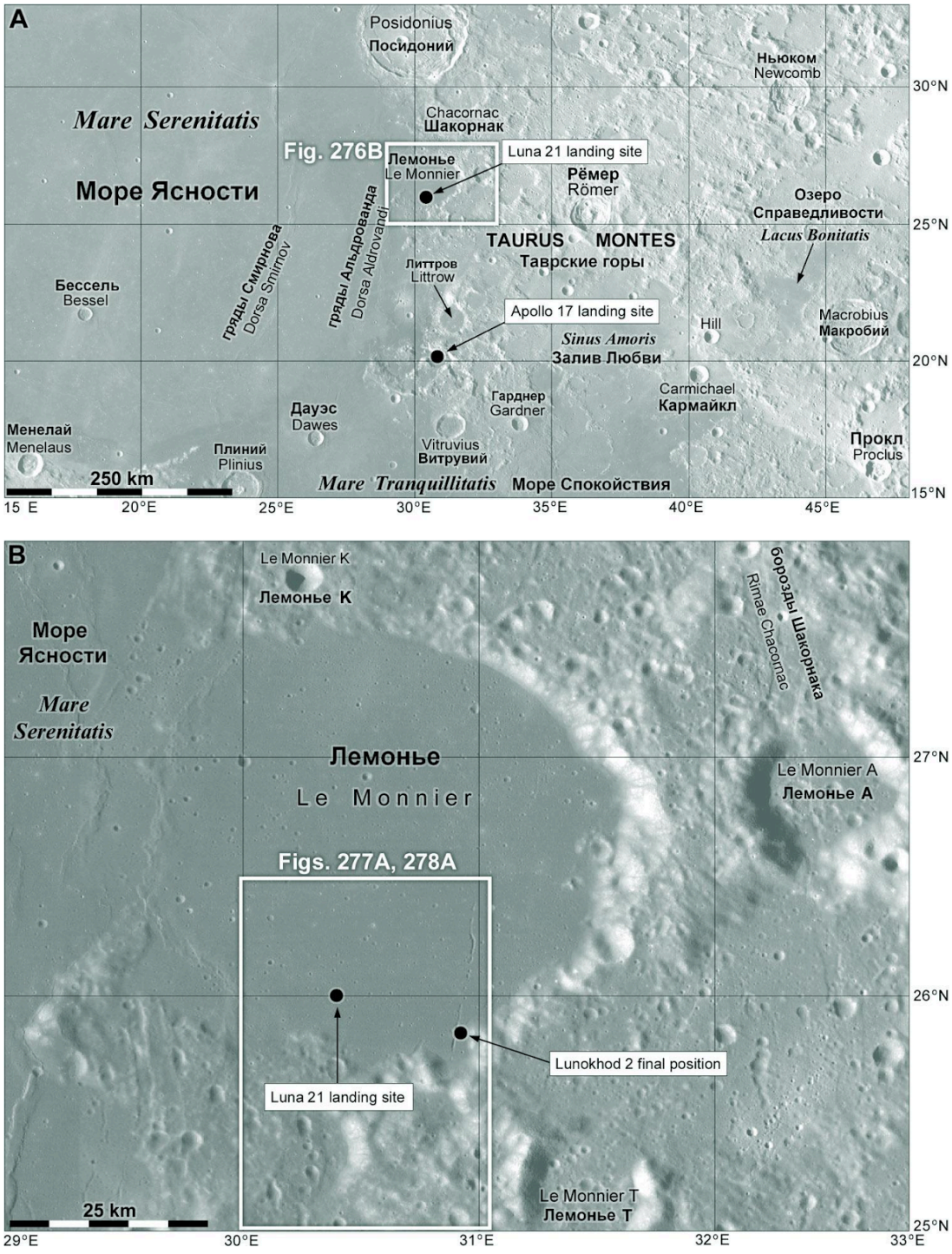


The synthetic panorama for the Luna 20 landing site projected into a circle (a modified polar projection). It does not match the partial Luna 20 panorama as well as I hoped because of lighting differences and the fact that it cuts off the foreground (I have not yet learned how to avoid that).

March 29, 2025 - #moon #luna21 #lunokhod2

I am still pondering Luna 20's images but for now we will look at the next Soviet mission to land on the Moon, Luna 21. It flew only a few weeks after Apollo 17 ended NASA's lunar exploration program, and for a few years the Soviet Union had the Moon to itself. Luna 17's rover had seen a few distant hills but Luna 21's rover, Lunokhod 2, would visit the boundary between plains and mountains in the most scenic place any Luna lander visited.

(Image on next page)

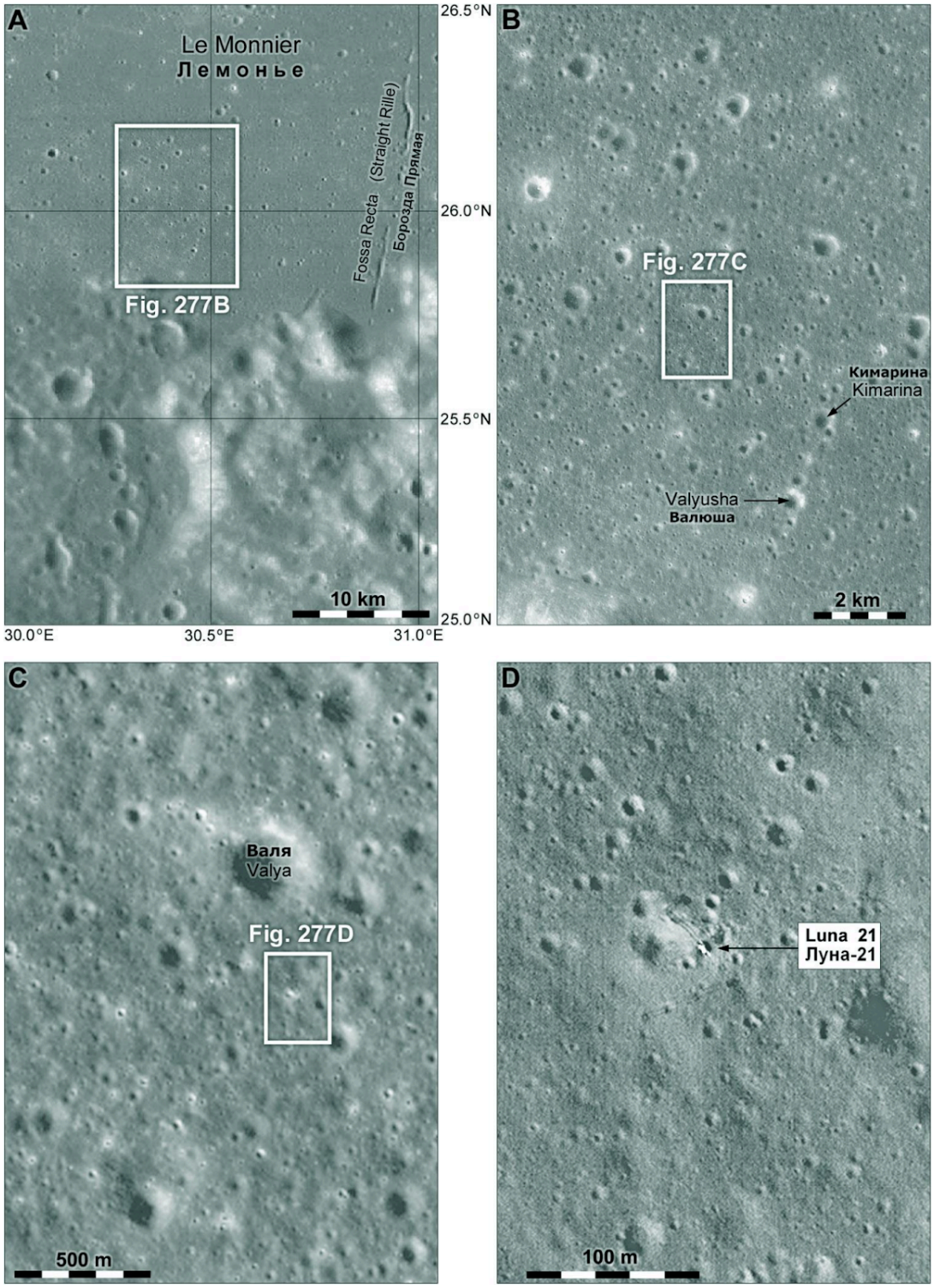


Two maps step in from a broad regional view to a more detailed view of he Luna 21 landing site. The top map covers a region a bit over 1000 km across on the eastern edge of Mare Serenitatis. The Apollo 17 landing site is in the lower middle part of the map and Luna 21 landed about 200 km further north. The lower map spans about 125 km centred on Le Monnier, a large crater on the edge of the Mare which is mostly filled with the Serenitatis lava flows.

March 30, 2025 -#maps #moon #luna21 #lunokhod2

Zooming in on Luna 21, here it is with tracks visible in the last image. There are a few feature names here - all of them unofficial except the name of the crater, Le Monnier. The Soviets did not name craters and other features at their sites until this mission, where a few names were given at the time, including 'Straight Rille', a linear valley. Crater names came only recently, all diminutives of womens' names. We will see a few more later.

(Image on next page)



Four maps which zoom in to the landing site of Luna 21. The last image at lower right shows tracks near the lander, made as the rover departed during the first lunar day. A few features are named, but none of these names are official.

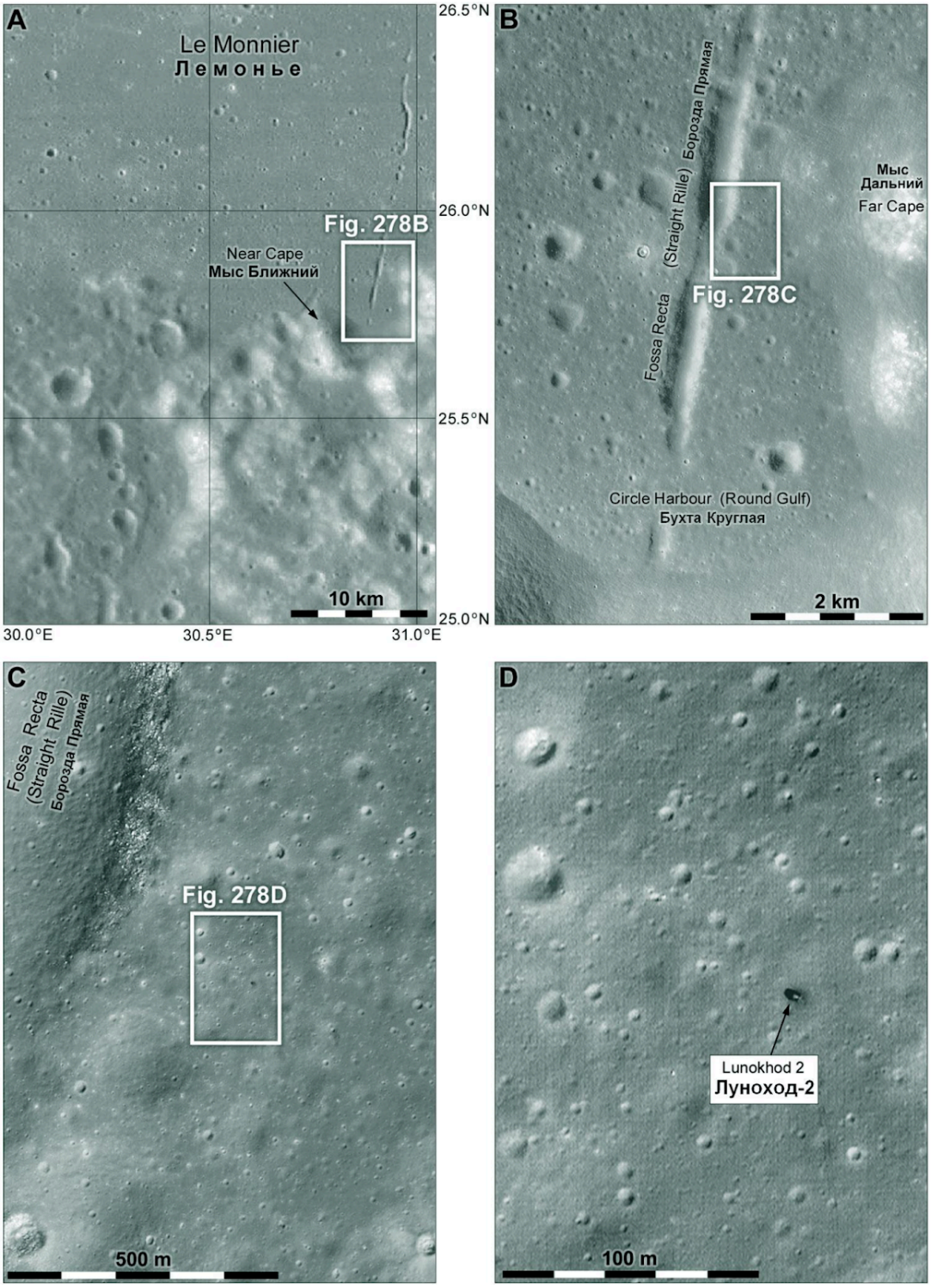
March 30, 2025 - #moon #luna21 #lunokhod2

Craters at the Lunokhod 1 site were named after men associated with the mission, first names in diminutive form. They were not used at the time of the mission but were put on a modern map and accepted by the IAU. These Lunokhod 2 names are women, probably people connected with the mission - a few are obvious to anyone who knows the people. They were proposed to the IAU quite a few years ago but nothing happened. Male bias? Probably.

March 31, 2025 - #maps #moon #luna21 #lunokhod2

Here is another of my zoom-in sequences locating Lunokhod 2. We know this now because of LRO and its amazing images. But before LRO - that's a gap of 36 years - the exact location was not known very well. The story is similar to that of Lunokhod 1: we had a map showing craters along the route but most features were too small to show up on the best images. This time the best images were from Apollo 15's Panoramic Camera...

(Image on next page)



A set of 4 nested maps zooming in on the final location of Lunokhod 2, the rover on the Luna 21 mission, made using LRO images.

March 31, 2025 - #moon #luna21 #lunokhod2

Apollo Panoramic Camera images are not as high resolution as LRO's Narrow Angle Camera images, but they are pretty good. However, this area was quite far north of the Apollo 15 orbit and was only seen obliquely at a greater distance than the point below the spacecraft. They did show the major features of the landscape: that linear valley, the main hills around he site. But the exact rover path could not be traced very well. Next we will look at earlier attempts.

April 1, 2025

Here:

https://planetarymapping.elte.hu/lunokhod-2-traverse-map/

is a map of the Luna 21 - Lunokhod 2 area in Le Monnier crater, published in 1973 by MIIGAiK, now known as the Moscow State University of Geodesy and Cartography. The path is overlaid as well as could be estimated at the time. Red circles along the route are lunar night stops. Curiously, the second night stop at lower left is in the wrong place, as we will see. One section was driven 3 times.

April 2, 2025 - #maps #moon #luna21 #lunokhod2

I have mapped every rover journey on the Moon and Mars, and I don't just want a wiggly line. I want to be able to say 'the rover was here on --- date', and 'here the rover made this observation'. That line on the MIIGAiK map is not enough. Luckily a map with that information was compiled, but it's hard to find. The part attached here was published in:

Vernov, S. N., ed., 1978. Uspekhi Sovetskogo Soyuza v issledovanii kosmicheskogo prostranstva. Moscow: Nauka.

(Image on next page)

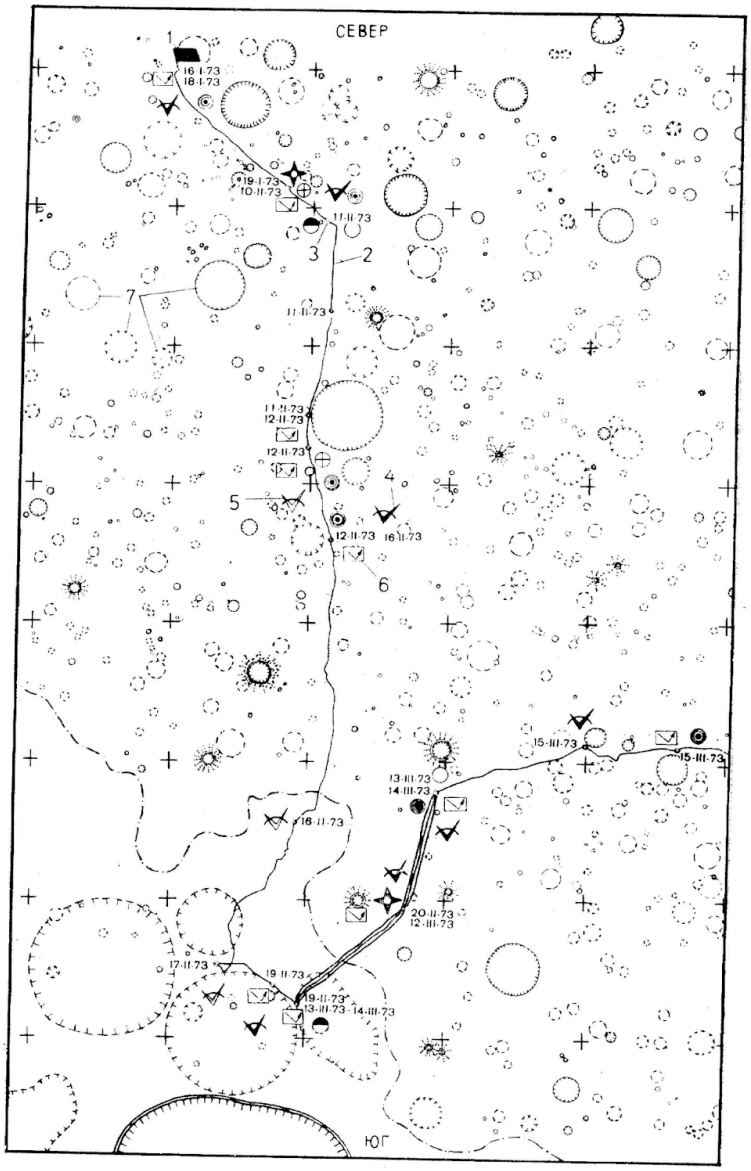
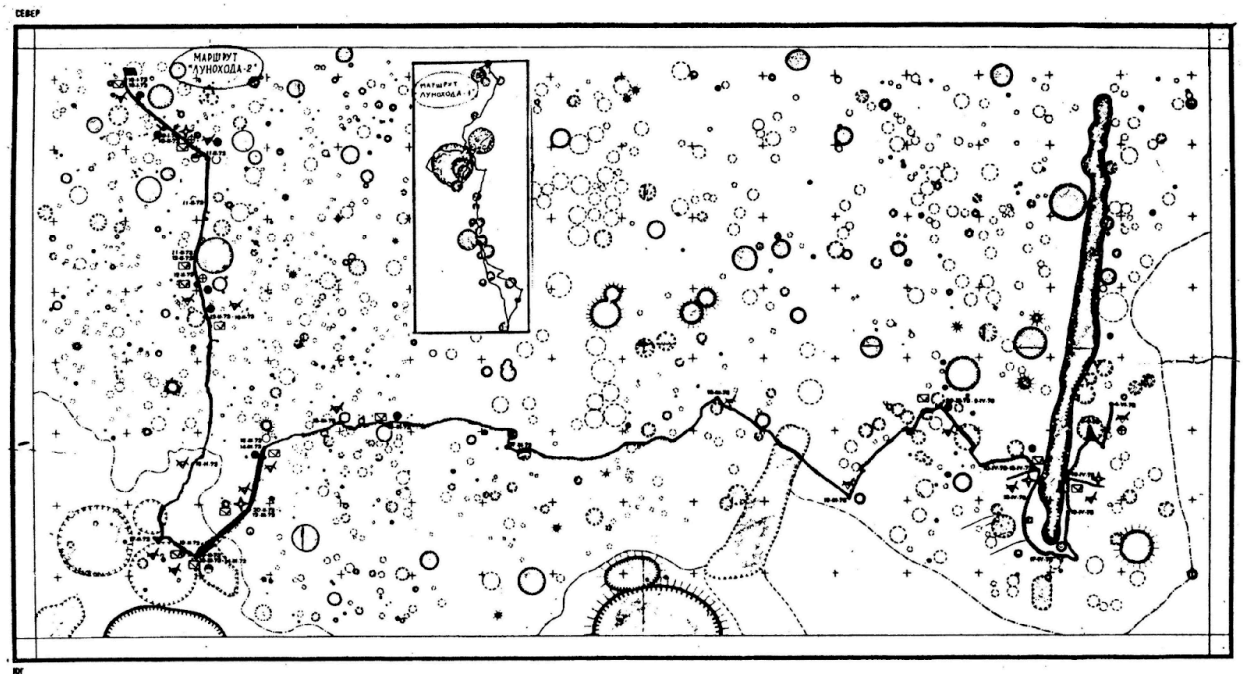


Рис. 18. Фрагмент топографической схемы маршрута «Лунохода-2»

Part of a detailed map of the Lunokhod 2 route with crater outlines and experiment locations. It is from a rather obscure source published in Moscow in 1978.

April 2, 2025 - #amps #moon #luna21 #lunokhod2

I didn't find it myself - it was sent by a friend. But the rest of the map has not been published, or if it has, I don't know where. Luckily my friend (hired personally by Sergei Pavlovich, and in those circles a last name is not necessary) sent me this scan, which is just barely legible but does allow a new map to be labelled. The hoops we have to jump through! I'm dealing with the same things now with China's Yutu-2 rover.

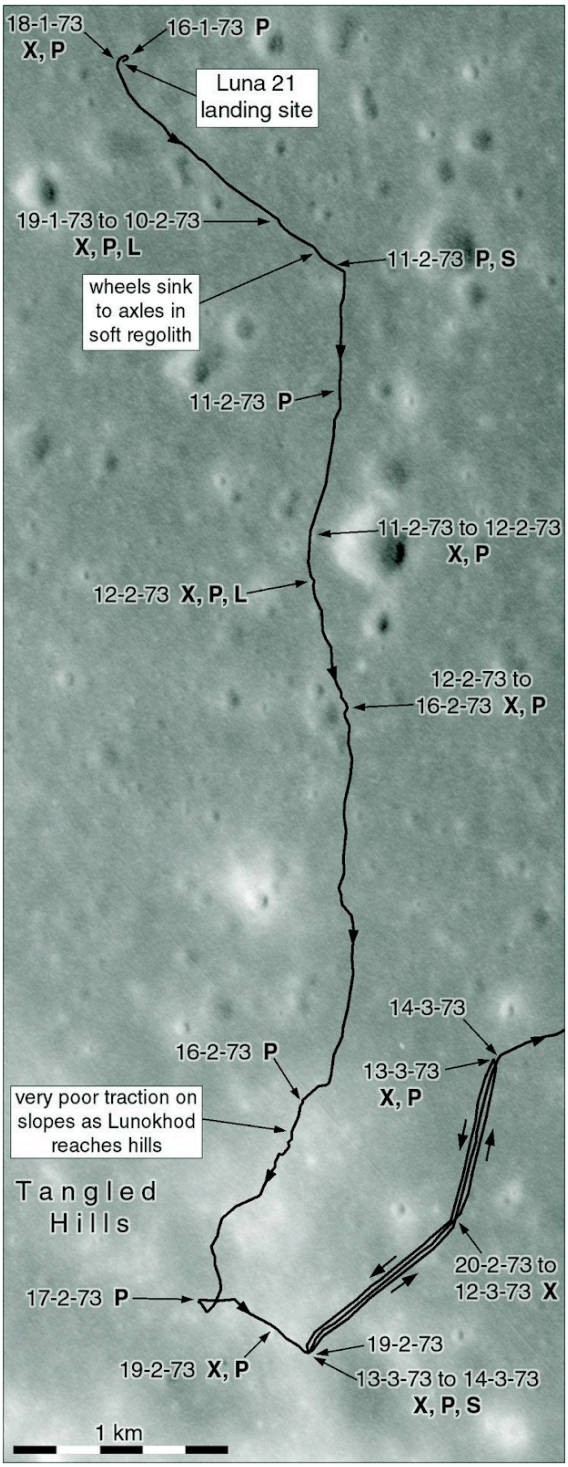


The rest of the previous Lunokhod 2 map, in a scan in which the test is only just legible.

April 3, 2025 - #maps #moon #luna21 #lunokhod2

Putting all this together - a base of Apollo 15 images, the Russian maps and location data - I made the maps which appeared in my old lunar exploration atlas. Here they are over two posts. This was the best that could be done at the time. Unfortunately I added some other details which were catastrophically wrong. But let's just enjoy these maps for the time being…

(Image on next page)

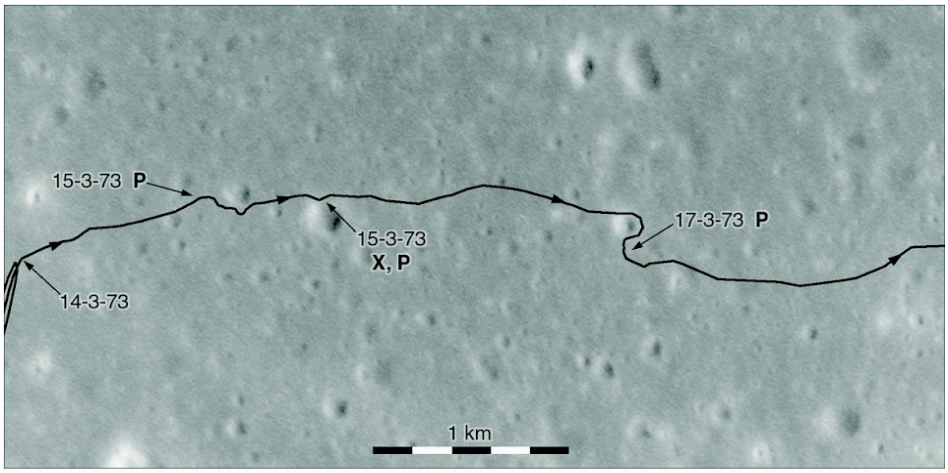


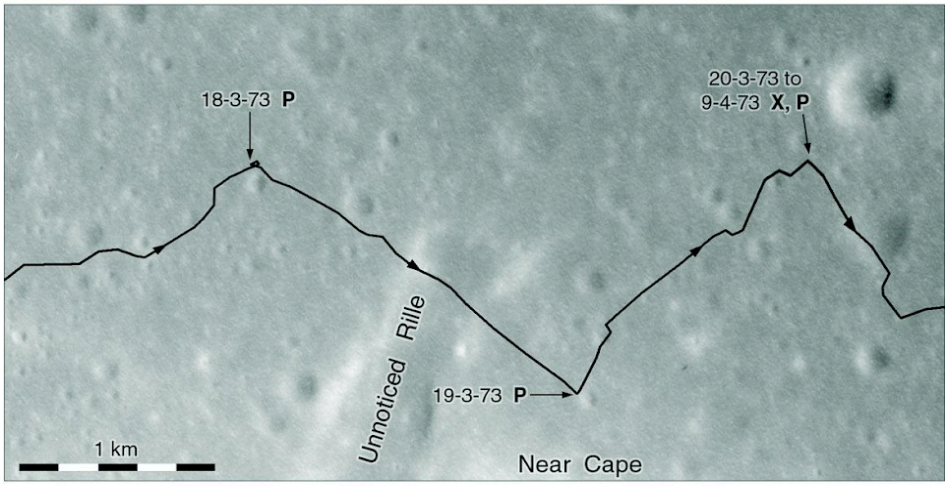
The first section of a map of the Lunokhod 2 route compiled from Apollo 15 images and the traverse details from Russian maps. This was in my atlas of lunar exploration in 2007. We can do so much better today.

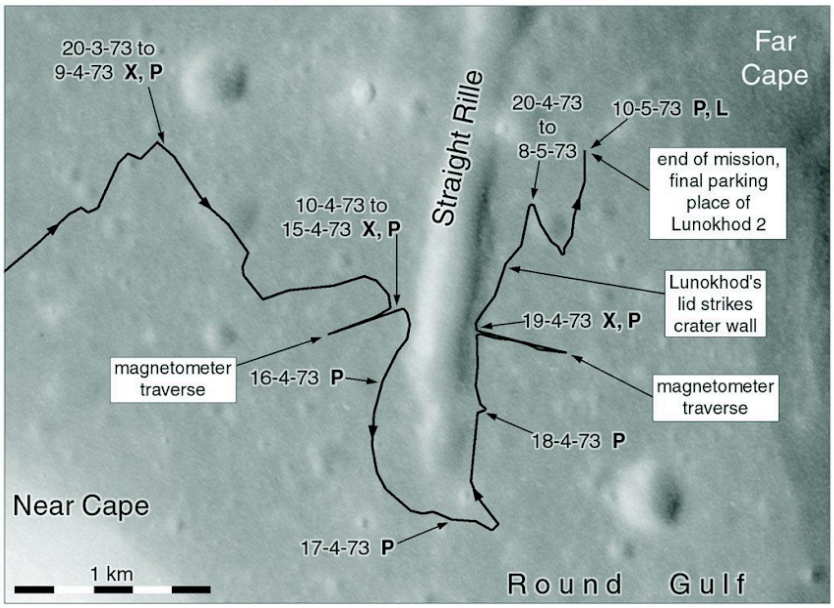
April 3, 2025 - #maps #moon #luna21 #lunokhod2

This is the rest of the Lunokhod 2 map as it was published in 2007, in three sections. The letters signify different experiments, but we will see more of that later. The problem with the map is the way the line is placed on the base map. Then its position could only be guessed, now we can actually see the tracks. Also, as we are going to see, many fine details are omitted here.

(Image on next page)







The rest of the Lunokhod 2 map in 3 sections, as originally published.

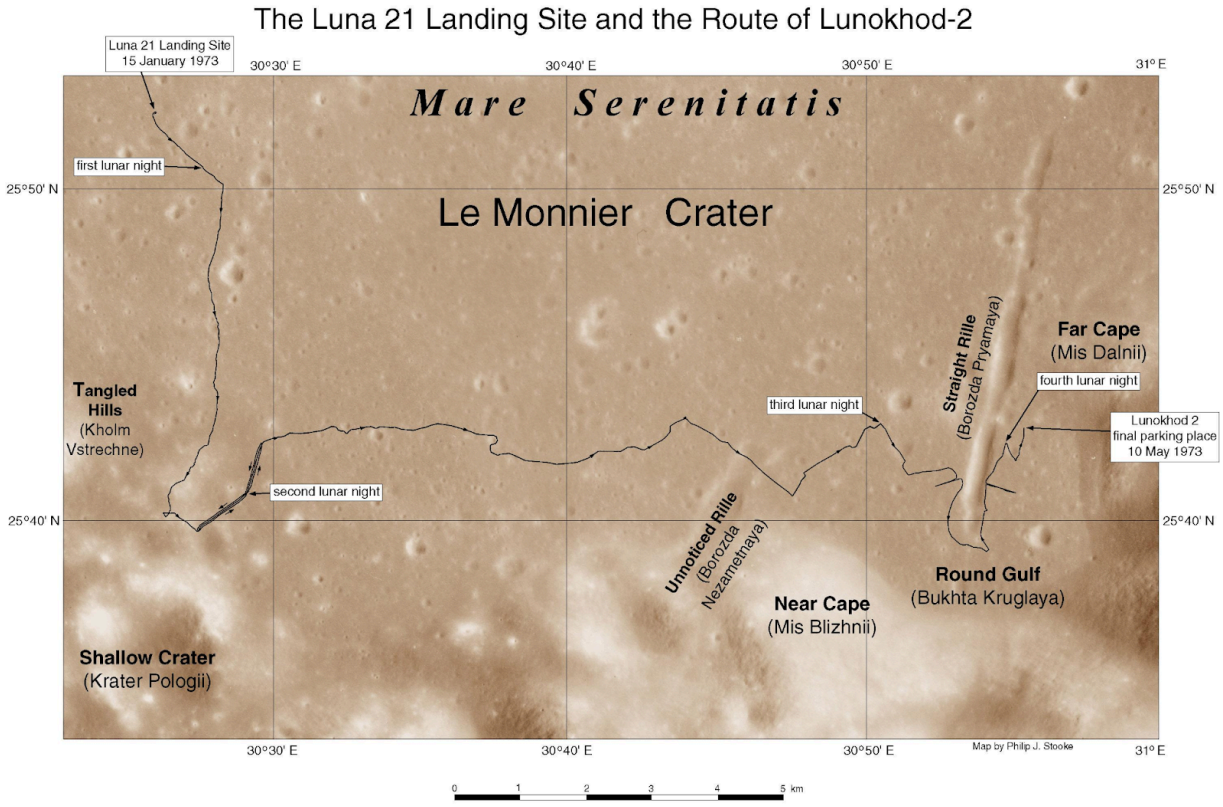
April 4, 2025 - #moon #luna21 #lunokhod2

Spacecraft in space or on the Moon or other bodies are owned by the entity responsible for creating them - ownership doesn't change because something stops working or is far away. So the Apollo hardware is owned by the US Government, and the Luna landers by Russia as the successor to the Soviet Union. Except for Luna 21 and Lunokhod 2. They were auctioned by Sotheby's for NPO Lavochkin in 1993 and bought by Richard Garriott for $68,500.

April 4, 2025 - #maps #moon #luna21 #lunokhod2

Garriott was a computer game pioneer and son of a Skylab astronaut. He flew to the ISS in 2008 with Space Adventures. Round about that time (my Moon book was out but LRO was not in orbit) he contacted me about a map of the Lunokhod 2 area. This is the map I made.

How will this compare with what LRO showed us?



A map of the Lunokhod 2 route made at the request of Richard Garriott, who owns them after NPO Lavochkin auctioned them in 1993. The map has the same base as the previous posts - Apollo 15 images - and shows the full route from the landing site at upper left to the end of drive at the right edge.

April 5, 2025 - #moon #luna21 #lunokhod2

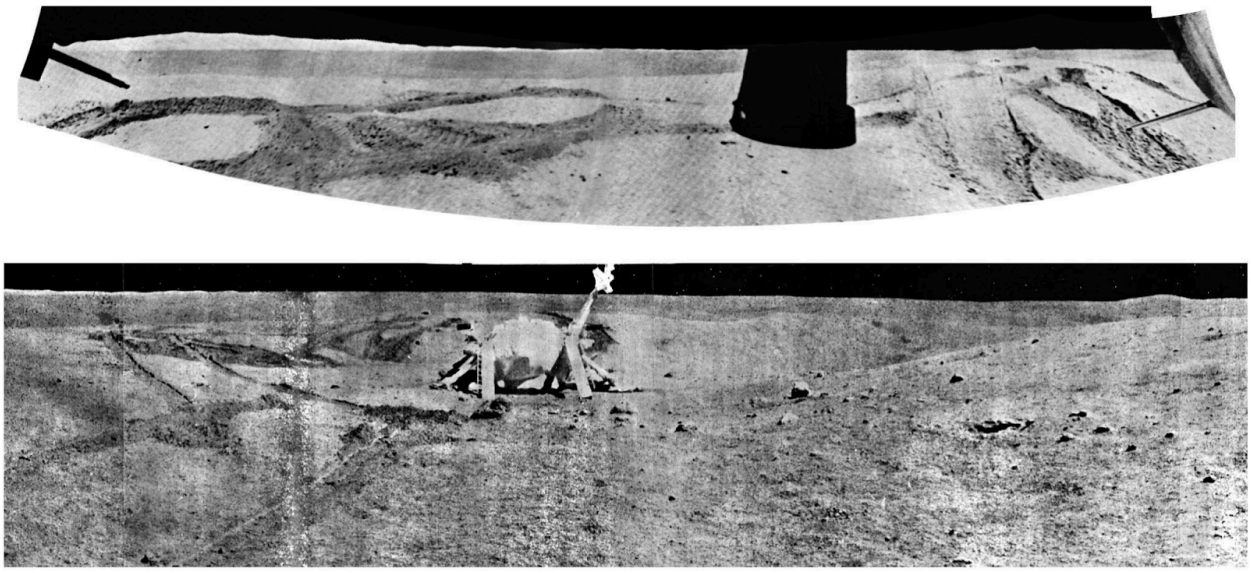
I can't avoid any longer the matter of my greatest error. Looking back, this was inexcusable, but at the time it seemed right. Here:

https://www.planetology.ru/panoramas/lunokhod2.php

are the Lunokhod 2 panoramas. But when I was working on my Moon book they were not available and people relied on published versions. I have told before how I found 1 or 2 cases of Lunokhod 1 panoramas printed in reverse (mirror-image), and began to imagine it everywhere. This is where bad things happened.

April 5, 2025 - #moon #luna21 #lunokhod2

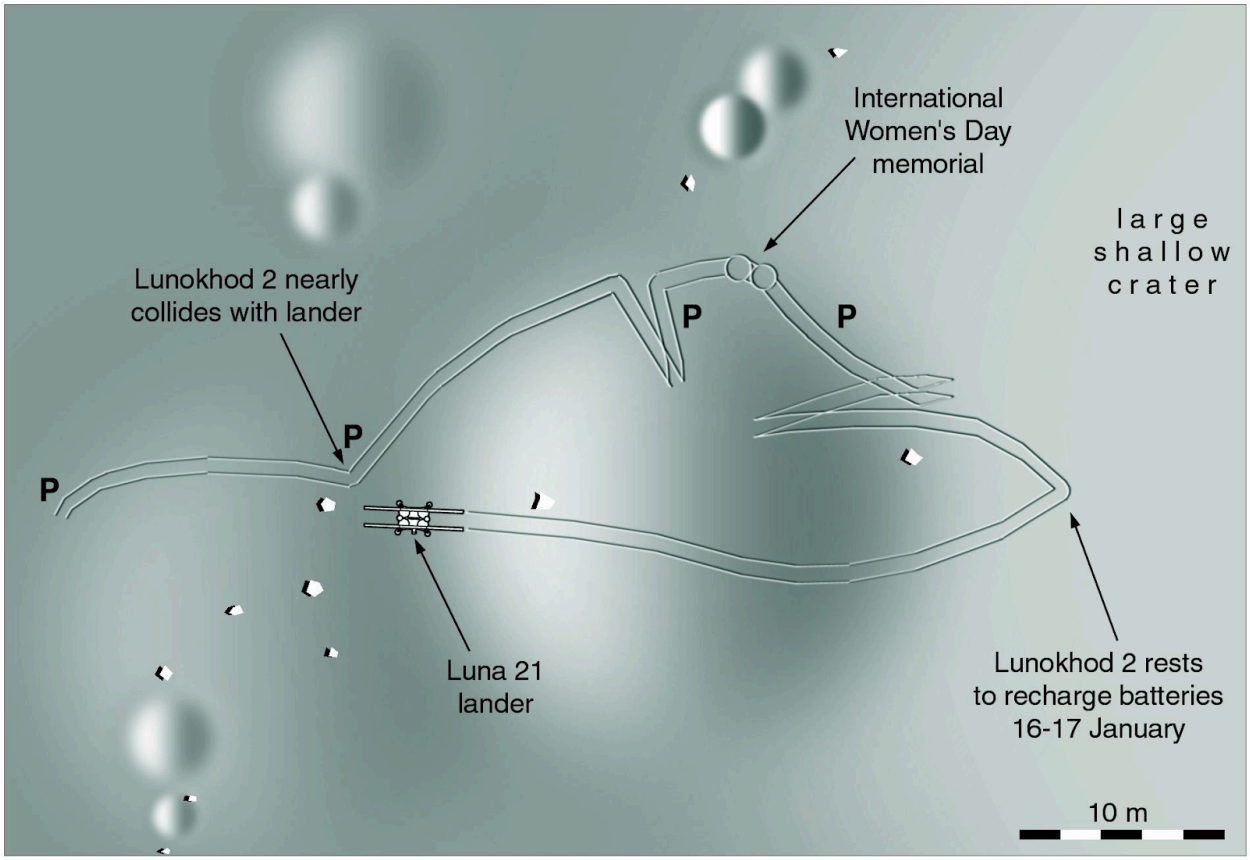
Here are two Lunokhod 2 pans from my Moon book, and if you check them against the linked source you will see they are both flipped left-right. The top one shows a 'figure 8' sign in the tracks, said to be for International Women's Day, though made in January. I wanted to make a map of the landing site and these plus 1 or 2 more images were all I had to go on. If you use flipped images to make a map it's going to be flipped too. You can see where this is going...



Two panoramas from Lunokhod 2 showing the rover tracks close to the landing site. The top one has a 'figure 8' shape in the tracks which was represented as an International Women's Day (March 8th) memorial, though it was made in January. Both images are accidentally flipped left-right.

April 5, 2025 - #maps #moon #luna21 #lunokhod2

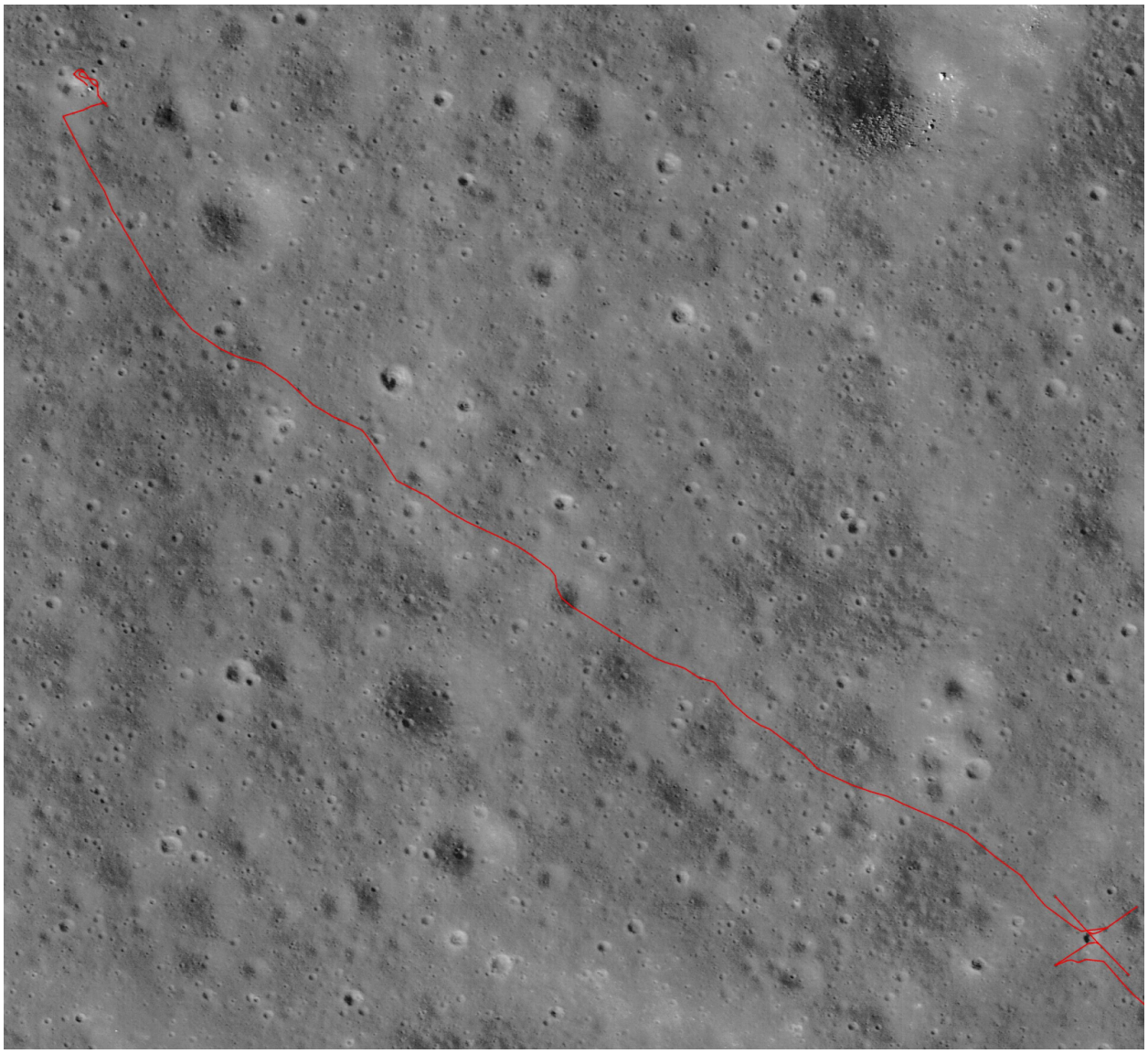
Sadly there was no big official report on the mission as we had for earlier landers. It would have set me straight. So I blundered atrociously and made this awful map. Now I can correct the story. Oddly I received very little flak for this even from my Russian colleagues (though I expect they made merry about it over a glass of vodka in my absence). Now you know how much trust you can put into anything I say. Now we can move on to what LRO revealed.



A map of the Luna 21 landing site made using the flipped panoramas and therefore also flipped. It shows the lander (in the wrong orientation) and tracks (in the wrong places). Despite all its flaws the problem was not caught and it appeared in my old Moon book. A new project is going to correct everything.

April 6, 2025 - #moon #luna21 #lunokhod2

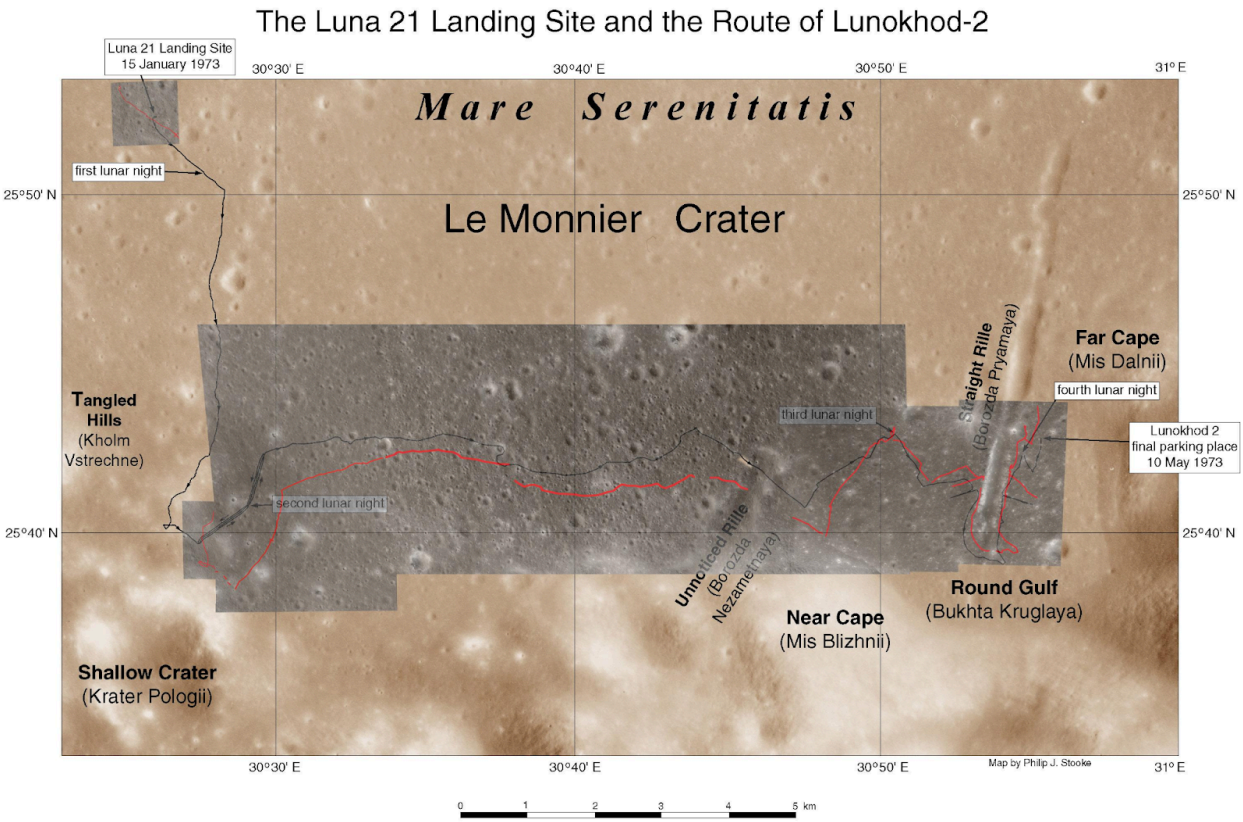
That's not even my last blunder concerning Lunokhod 2, but we'll come back to that. LRO began imaging in 2009 and by 2010 there were enough images of the landing area to map the rover tracks. Zoom all the way in and tracks are easy to see. Zoom out to the full image and they are invisible but you can see the larger craters. So I drew red lines over the tracks to make the path easy to see at any scale. This image covers the first lunar day.



An LRO NAC image (number is in the file name if you save it) covering the area of Lunokhod 2's first lunar day. The landing site is at top left, the first night position is at bottom right. The tracks are highlighted in red for easier viewing.

April 6, 2025 - #maps #moon #luna21 #lunokhod2

I did this for most of the path and then overlaid these images on the Garriott map to compare the old and new paths. Here is the result. The old map looked good but it was offset from the true position. The most interesting observation is that the rover drove further than previously thought. It started further north and drove further south than the old map showed (left edge), and ended (far right) further north again. Then it got more interesting...



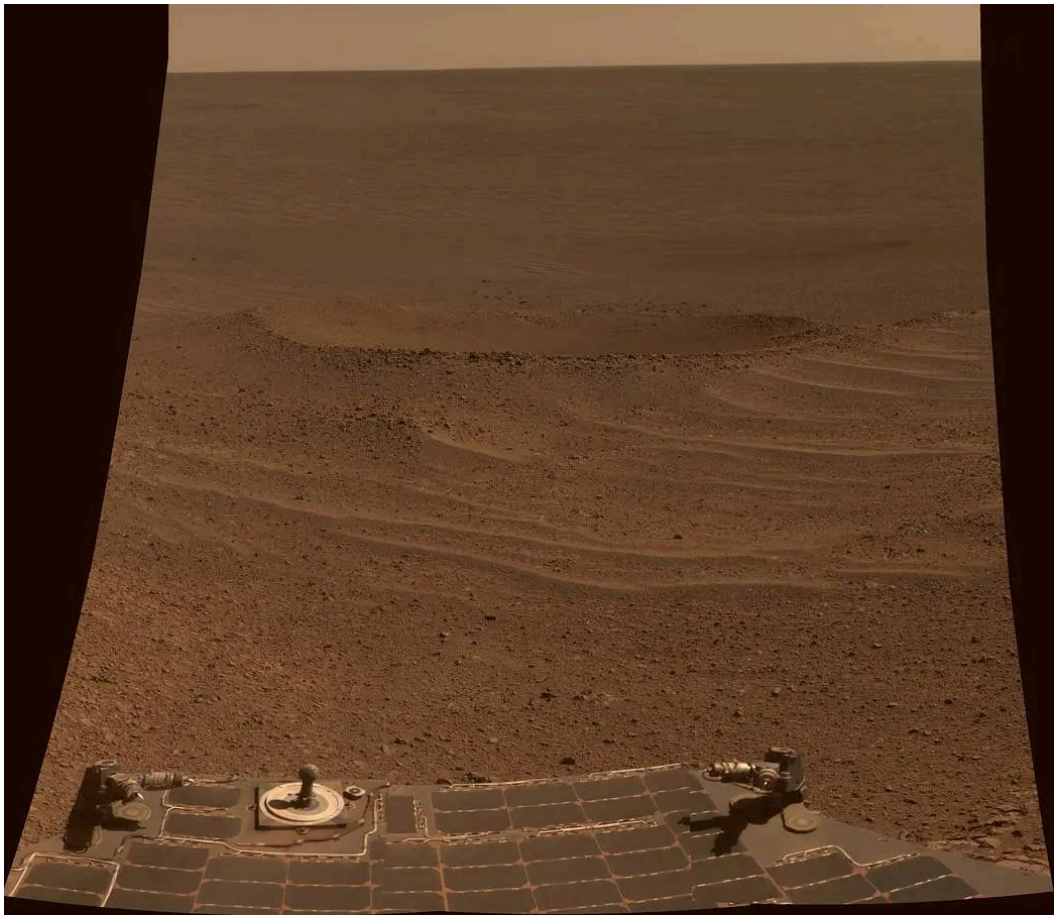
The map of the landing area is here overlaid with greatly reduced LRO images. They are aligned with craters and other features. The tracks are shown in red and do not match the old tracks very well. The shape is roughly correct but the path is offset, typically by about 500 m.

April 7, 2025 - #moon #luna21 #lunokhod2

Lunokhod 2's drive distance was estimated at 37 km in the 1970s. In the summer of 2013 the Mars rover Opportunity was nearing that distance. Would it break the record? Steve Squyres contacted me about it, having seen my map work on unmannedspaceflight.com. I told him at once that the map I just posted showed that it must have driven a bit further, and put him in tough with the Russians who were making new maps of their own. The final analysis showed a distance of 39 km.

April 7, 2025 - #moon #luna21 #lunokhod2 #opportunityrover

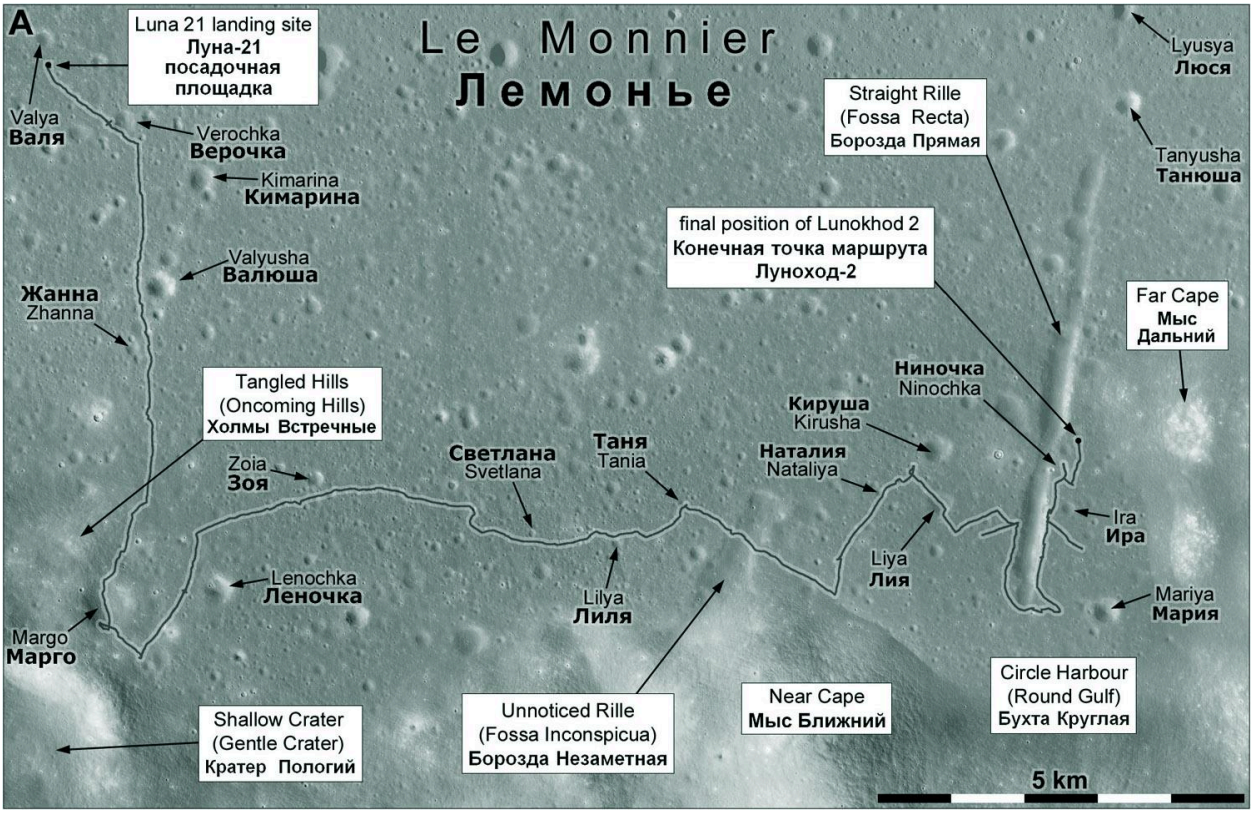
So finally on Opportunity's sol 3643 (24 April 2014) the veteran rover passed the Lunokhod 2 distance (taken as 39.1 km to exceed the range of uncertainty around the distance). A nearby crater was named Lunokhod 2. Here it is.



Lunokhod 2 crater on Mars, imaged by the Mars rover Opportunity as it exceeded the total distance of Lunokhod 2, 39.1 km, in April 2014.

April 8, 2025 - #maps #moon #luna21 #lunokhod2

We will now start looking at the LRO results for Lunokhod 2. Tracks are easily visible in most areas so mapping is no longer a problem. To begin, here is an overview of the traverse with all the informal names given to features. Craters are Russian female names, sometimes in the diminutive form. If you knew Kira Shingareva you might wonder why there is no Kira, but that name is already in use for a small crater near Tsiolkovskiy.

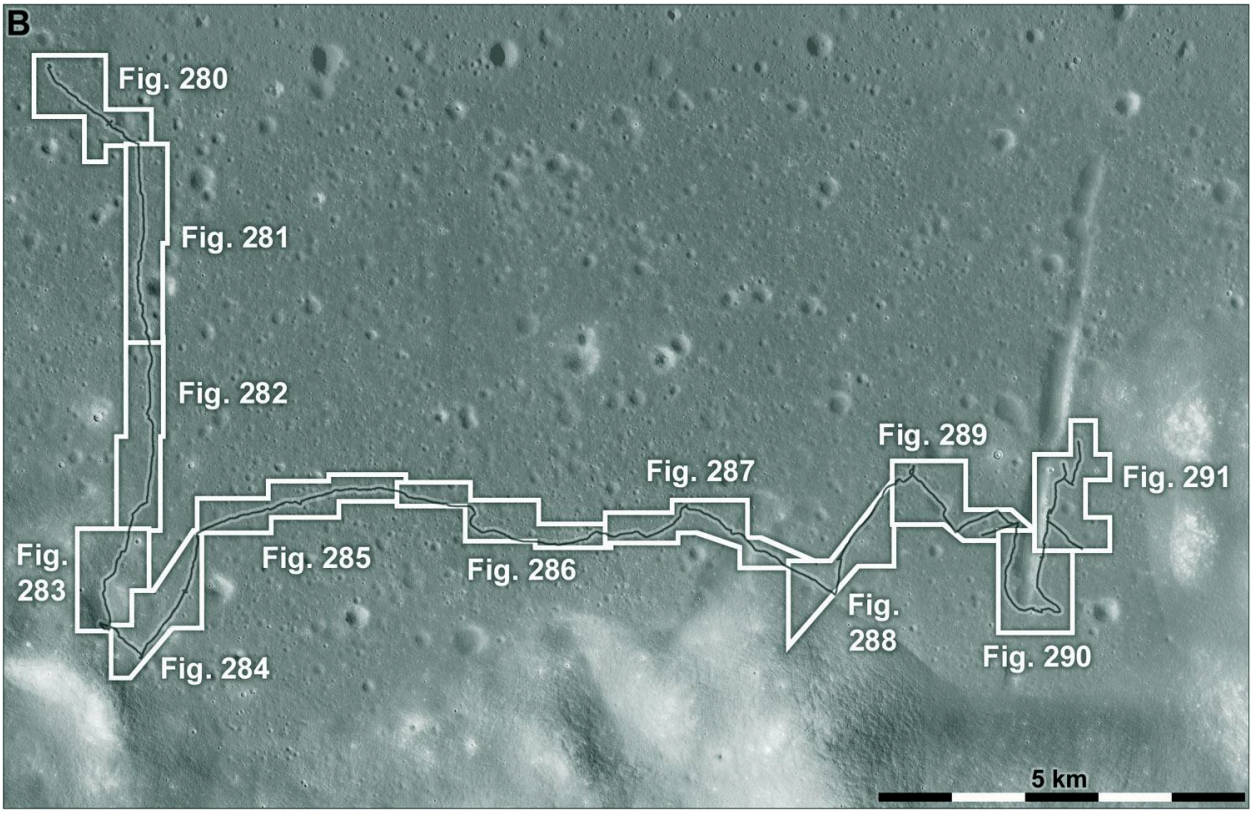


A map of the Lunokhod 2 region with informal names of craters and other features. The rover began at upper left, drove to lower left, then across the lower part of the map to the right edge, and it was driving north when the mission ended. A long straight trough runs south to north up the right side of the map.

April 9, 2025 - #maps #moon #luna21 #lunokhod2

As with my Apollo EVA maps and Lunokhod 1, this mission requires quite a few maps to cover it in detail. This index shows how they are arranged. The figure numbers are placeholders (final numbers will be larger) for my current project, which I hope to be revealing late this year.

This map has exactly the same base as the previous post.

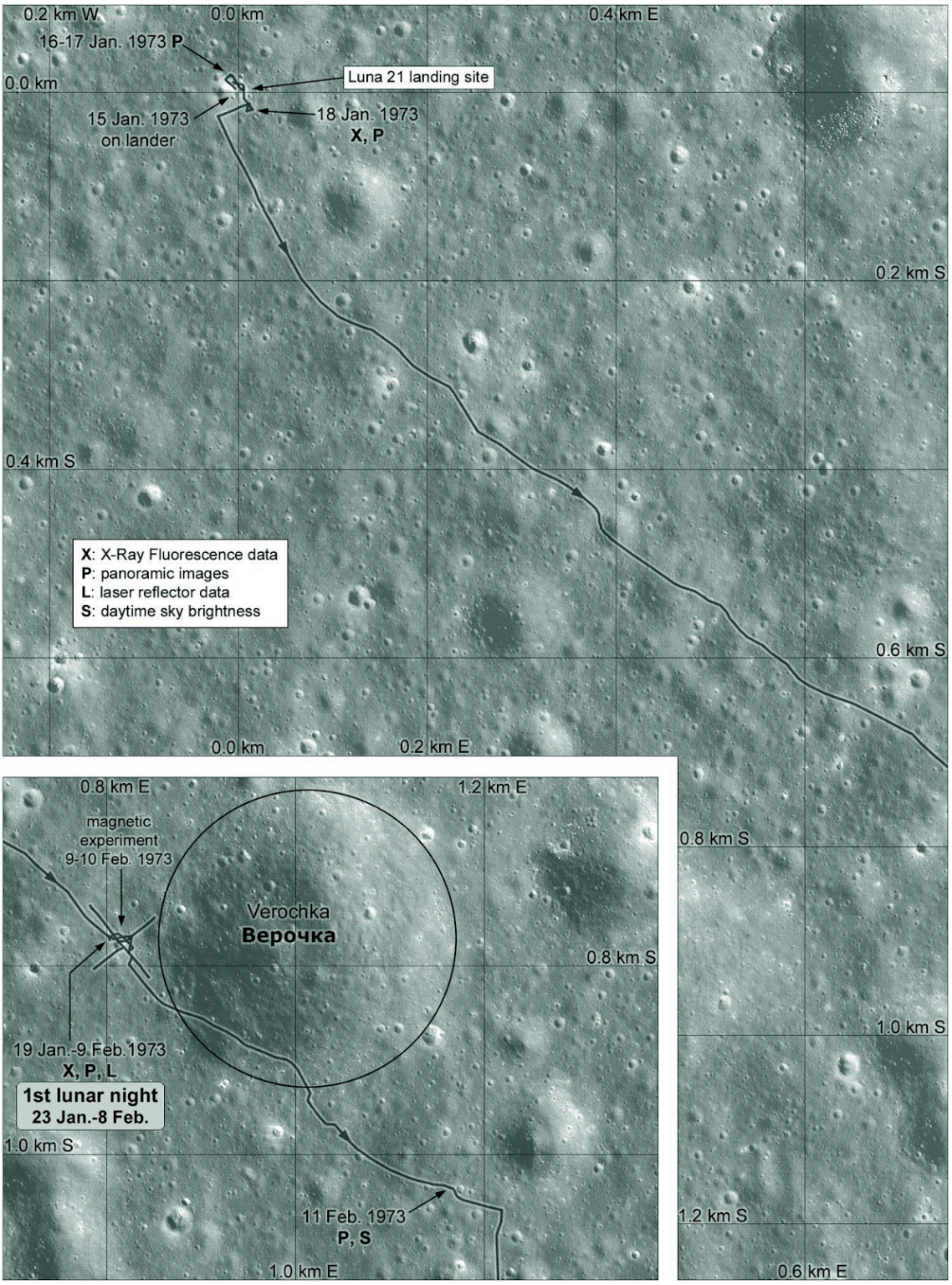


An index map for the posts to follow this one, covering the route of Lunokhod 2. The individual maps are sized as pages in a book or PDF document. Figure numbers are only placeholders.

April 9, 2025 - #maps #moon #luna21 #lunokhod2

Here is the first map. It starts at the landing site and ends at the stop for the first lunar night, also showing activities at the start of day 2. The landing site map is very different from the map I made earlier - and we will look at it in more detail later. Quite a lot of different panoramic images were taken from the rover when it was on the lander and in the vicinity, enough that I was able to do something unique for either Lunokhod. We'll see it tomorrow.

(Image on next page)

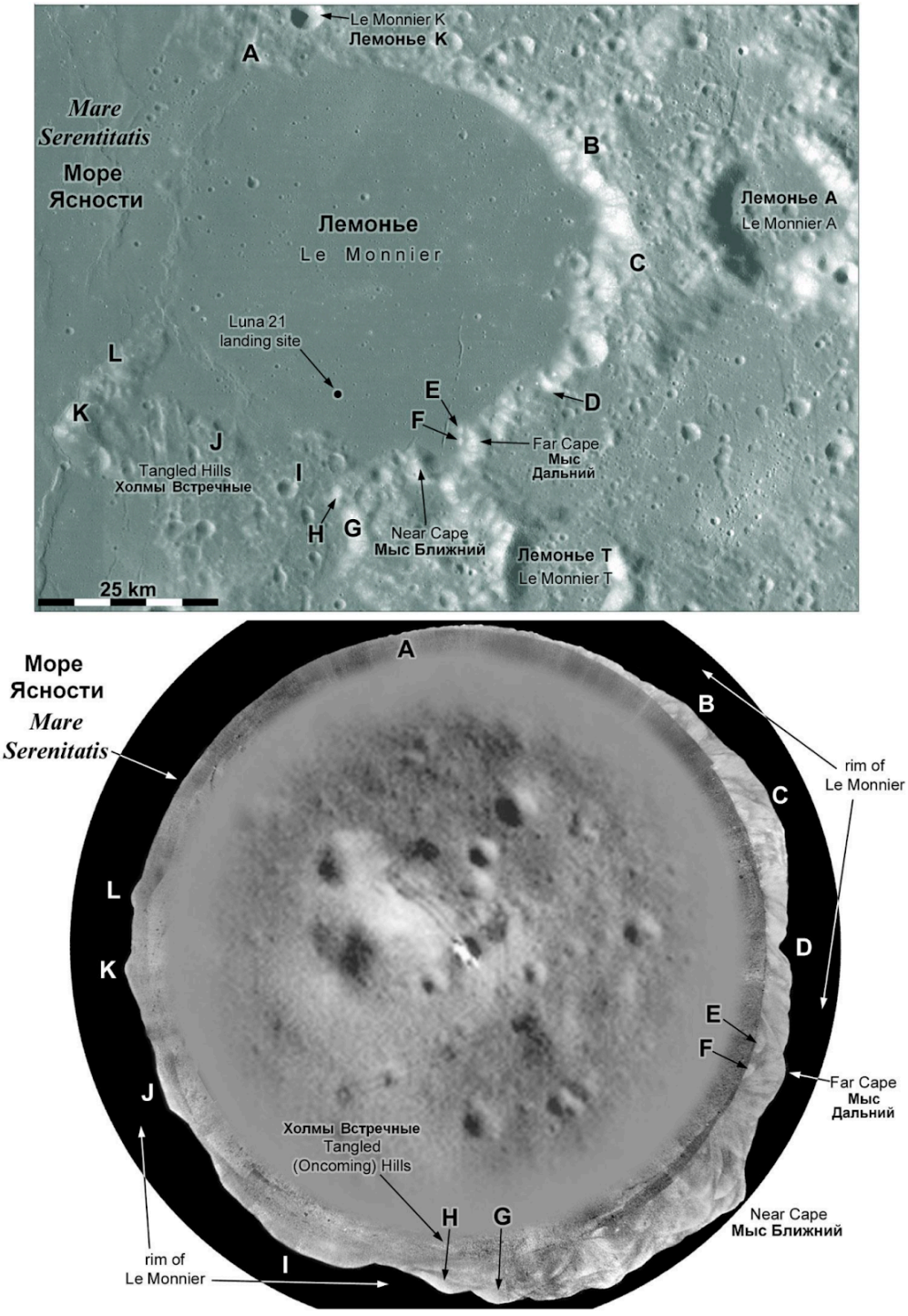


The first map of the Lunokhod 2 traverse. This map has an LRO NAC image base and a grid with 200 m spacing. The rover started at top left and drove down to bottom right, where its path is continued in an inset map.

April 10, 2025 - #maps #moon #luna21 #lunokhod2

Lunokhod 2 took several panoramas on the lander and near it. I posted a link to an online collection of those images. Between them they provided a full 360 view of the horizon. The long narrow images don't lend themselves to full landing site mapping and this is the only case I have found where a full horizon is visible. Here it is with a map to help match features. This resolved problems i had with imagined image reversal in the past.

(Image on next page)



At the top of this image is a map of Le Monnier crater, landing site of Luna 21. At the bottom is a full view of the horizon from the landing site, projected into a circle so azimuths to features on the map match the image. The images were taken from several different sites so their foregrounds don't match and have been removed.

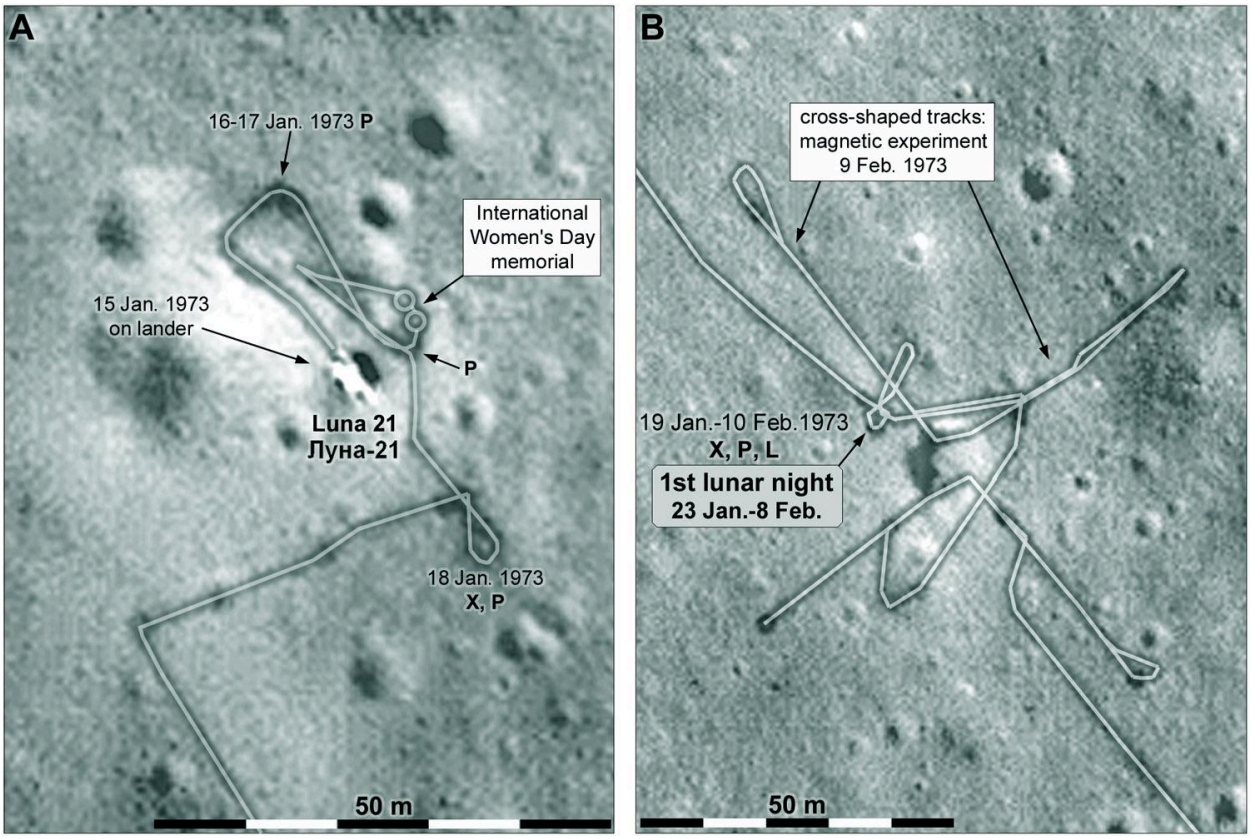
April 10, 2025 - #moon #luna21 #lunokhod2

The pictures were all taken close to the lander but not at exactly the same spot, so their foregrounds don't match and have been removed from the image. I replaced it with an enlarged view of the lander and tracks.

Tomorrow we will have a look at the actual landing site and that peculiar cross-shaped pattern of tracks at the night 1 location.

April 11, 2025 - #maps #moon #luna21 #lunokhod2

Here are two maps of those special areas at each end of the first lunar day's drive for Lunokhod 2, shown on enlargements of the best LRO image. The drive around the lander can be mapped properly now. The map at right shows where Lunokhod 2 spent the lunar night, and what it did early the next lunar morning. It drove a complicated path around a small crater in a cross-shape, measuring the magnetic field along each arm of the cross.



Two maps of activities by Lunokhod 2. At left is a map of the rover's drive around the lander just after landing. At right is the position of the first lunar night stop, plus the magnetometer traverse done early on the morning of the second lunar day. This involved driving four arms of a cross-shape with a small impact crater at its centre. The rover accidentally drove into the crater and struggled to get out.

April 11, 2025 - #moon #luna21 #lunokhod2

The magnetometer measures the local magnetic field and any field generated by the rover itself. It drives each arm of the cross in two directions. The local field and rover field can be separated by measuring twice with the rover in opposite orientations. The idea is to see if the local field is disturbed by the impact crater. The rover accidentally drove into the crater and struggled to get out - more on this tomorrow.

April 12, 2025 - #moon #luna21 #lunokhod2

Here is the story of the rover's accidental drive into that crater:

https://www.smithsonianmag.com/air-space-magazine/time-soviet-moon-rover-refused-stop-180967884/

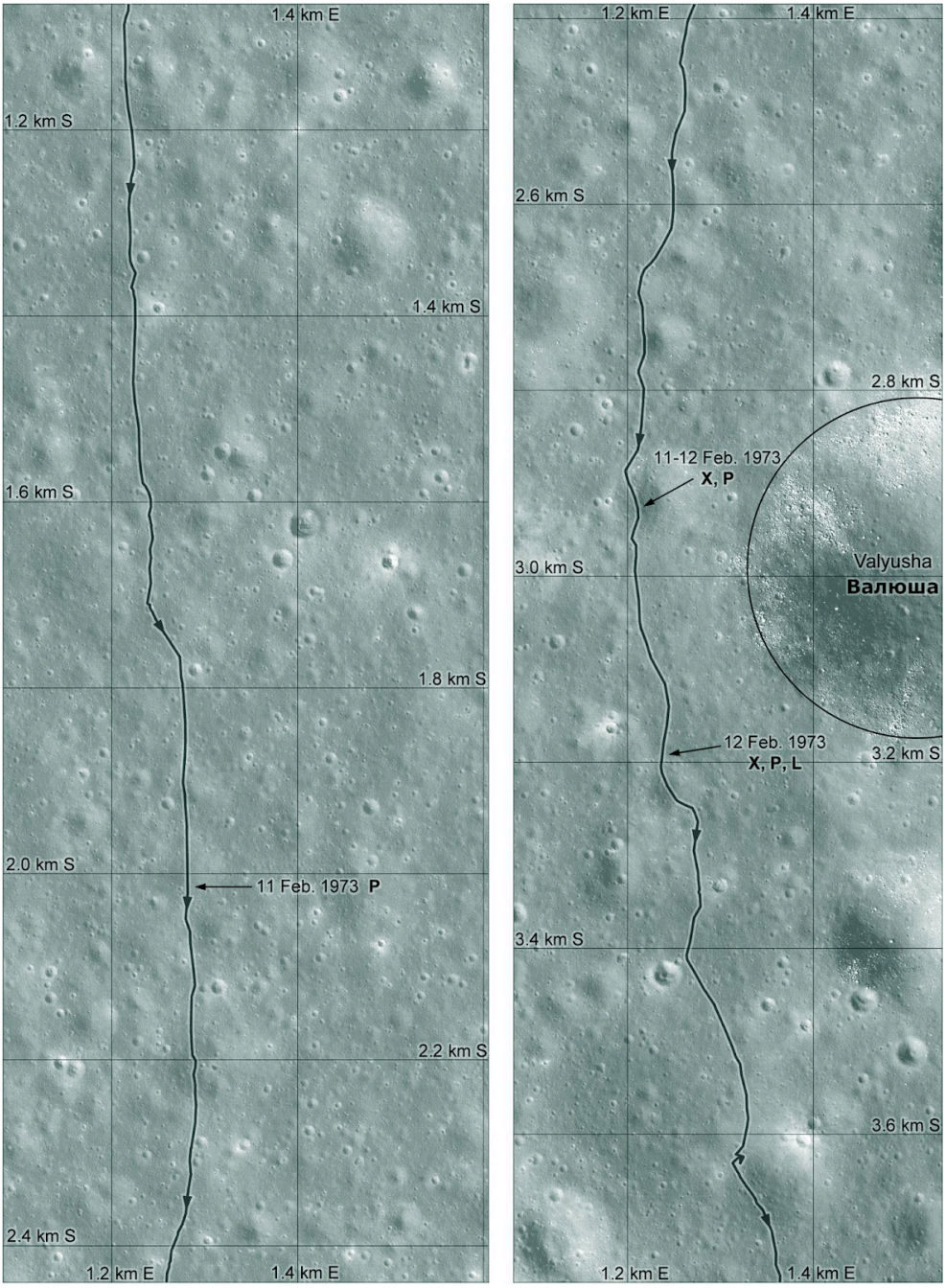
And here is an image of the convoluted tracks in the crater made during the attempt to climb out of it. I have to update my map with these tracks, now that I look at it again.

Tracks made by Lunokhod 2 as it drove into a small crater by mistake and struggled to get out, early on lunar day 2 of its traverse. The tracks are very deep where the rover crossed the crater rim, showing very soft regolith.

April 13, 2025 - #maps #moon #luna21 #lunokhod2

The next section of the Lunokhod 2 route map depicts a long drive due south. The rover team wanted to reach the hills visible on the southern horizon, the closest examples of material from the rim of Le Monnier crater. There's nothing unusual about this map until you look at the dates along it. Check back to the first map. Lunokhod 2 left the magnetometer area on 11 February, 800 m south of the lander. By the end of that Earth day it was 2.9 km south…

(Image on next page)



A map in two panels showing part of the drive on Lunokhod 2's second lunar day. The rover was driven south in almost a straight line towards the hills visible on the southern horizon.

April 13, 2025 - #moon #luna21 #lunokhod2

That is over 2 km in one Earth day of driving, and I think that means in one shift at the control centre in Simferopol, Crimea. And that is not the record.

Here:

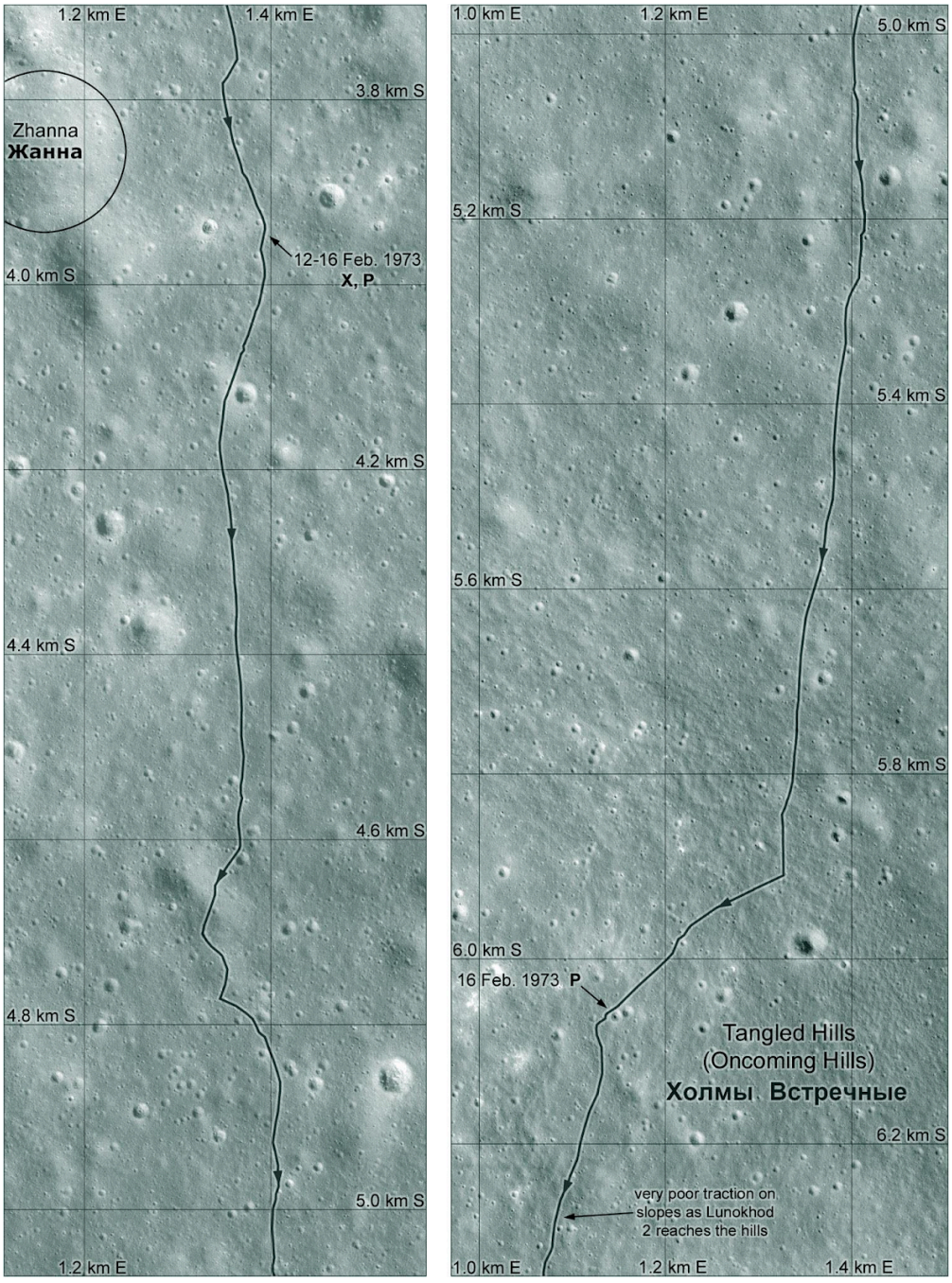
https://www.higp.hawaii.edu/~gjtaylor/GG-673/Moon/Class%20lectures/Lunokhod_2.pdf

is a nice presentation about Lunokhod. In slide 10, the person at right (standing) referred to as 'I - his deputy', is Sasha Basilevsky, who is also the author of the diary page in slide 14. Sasha is still researching and publishing today.

April 14, 2025 - #maps #moon #luna21 #lunokhod2

This is map 3 in my Lunokhod 2 sequence. It looks similar to the last one, but at about 5.4 km south a subtle texture change marks a break in slope as the land starts to rise into the hills (variously called 'Tangled Hills' or 'Oncoming Hills' in different maps). These are not steep slopes but the looser regolith offered poor wheel traction. At 3.95 km south the rover stops for 4 days over local noon when a lack of shadows makes driving difficult.

(Image on next page)



Map 3 of the Lunokhod 2 sequence. It is in 2 panels, following the north to south path of the rover. Near the crater Zhanna the rover stopped for 4 days over local noon when driving visibility is poor. in the second (right) panel the rover begins to climb a subtle slope into a range of low hills.

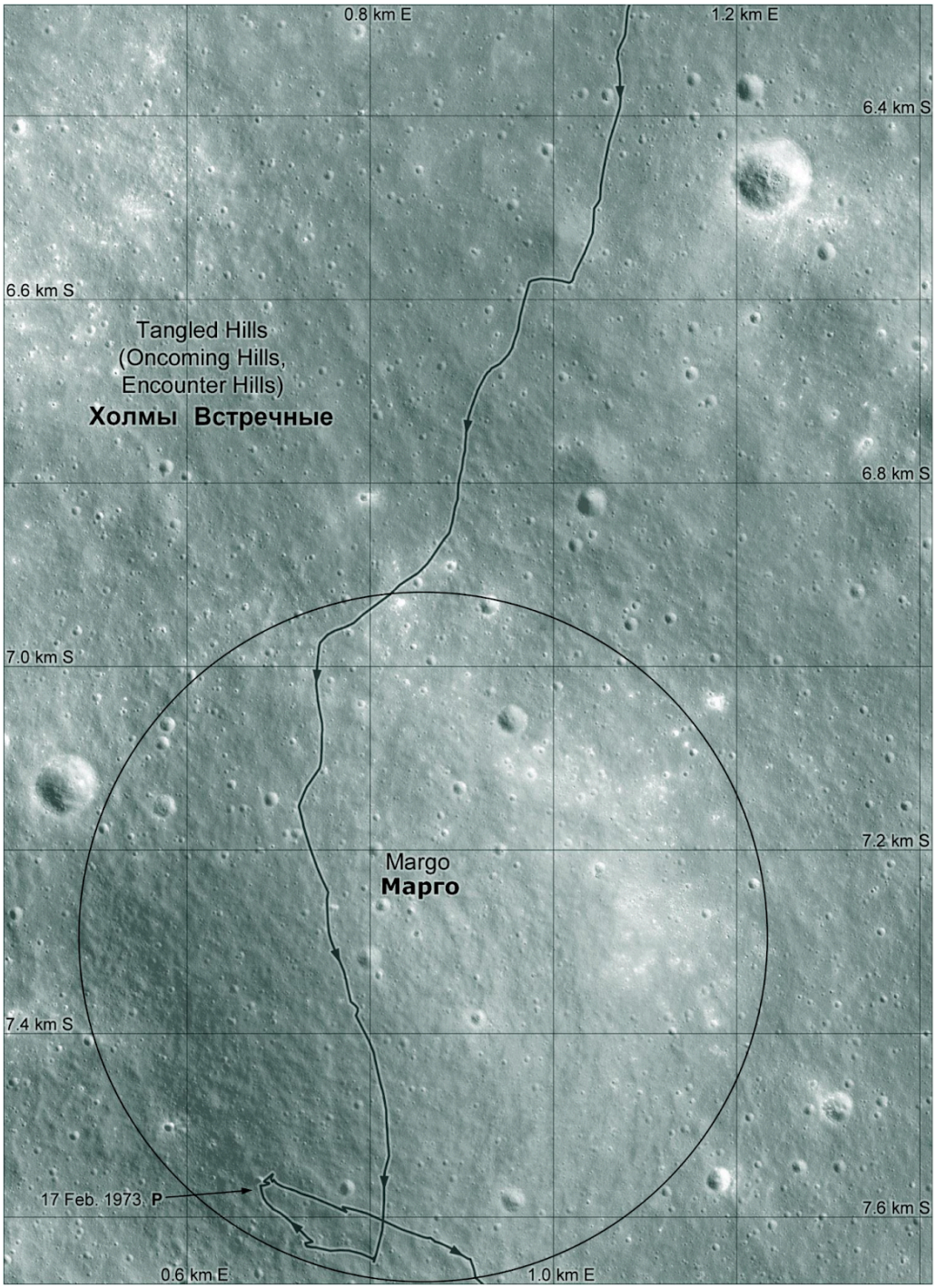
April 14, 2025 - #moon #luna21 #lunokhod2

That mid-day pause was also made by China's two rovers. Here on the Lunokhod 2 map the pause occurs near a crater called Zhanna (remember these are still informal names). Lunokhod 1's crater names were of actual men associated with the rovers. If that is true of these female names, Zhanna might refer to Zhanna Rodionova, a researcher at the Sternberg State Astronomical Institute, part of Lomonosov Moscow State University, a prominent planetary cartographer.

April 15, 2025 - #maps #moon #luna21 #lunokhod2

The 4th section of the Lunokhod 2 route map brings us well into the hills, and into a crater called Margo, about 750 m across. At the south edge of the map the rover tracks show a struggle to climb out of the crater, eventually resolved by driving east, more diagonally up the slope. Reports that Lunokhod 2 imaged a crescent Earth above the hills might refer to this location, where the slope might allow the cameras to see Earth to the southwest.

(Image on next page)



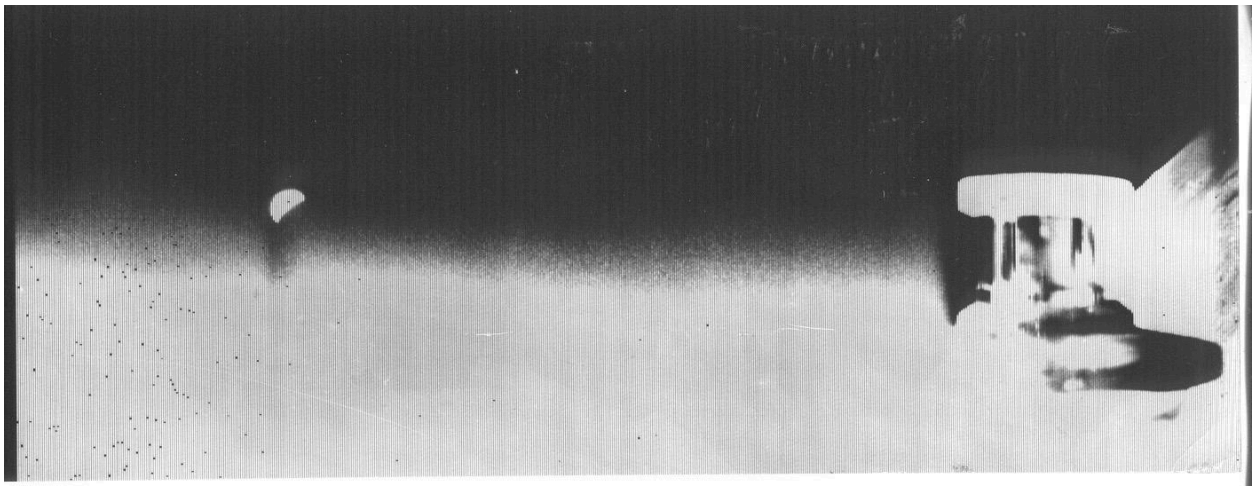
Part 4 of the Lunokhod 2 route map. Here the rover enters the map at the top (north) and drives south, entering a 750 m diameter crater called Margo. It struggles to climb its southern rim and exits diagonally up the slope to the southeast.

April 15, 2025 - #moon #luna21 #lunokhod2

I had never seen that crescent Earth image until early this year when a follower very helpfully pointed out to me a part of the Lavochkin website:

https://www.laspace.ru/ru/activities/projects/

which had the image. There are plenty of images in those pages in the Gallery section for each mission, not all labelled correctly. This one was mislabelled as from Luna 16. Here it is.

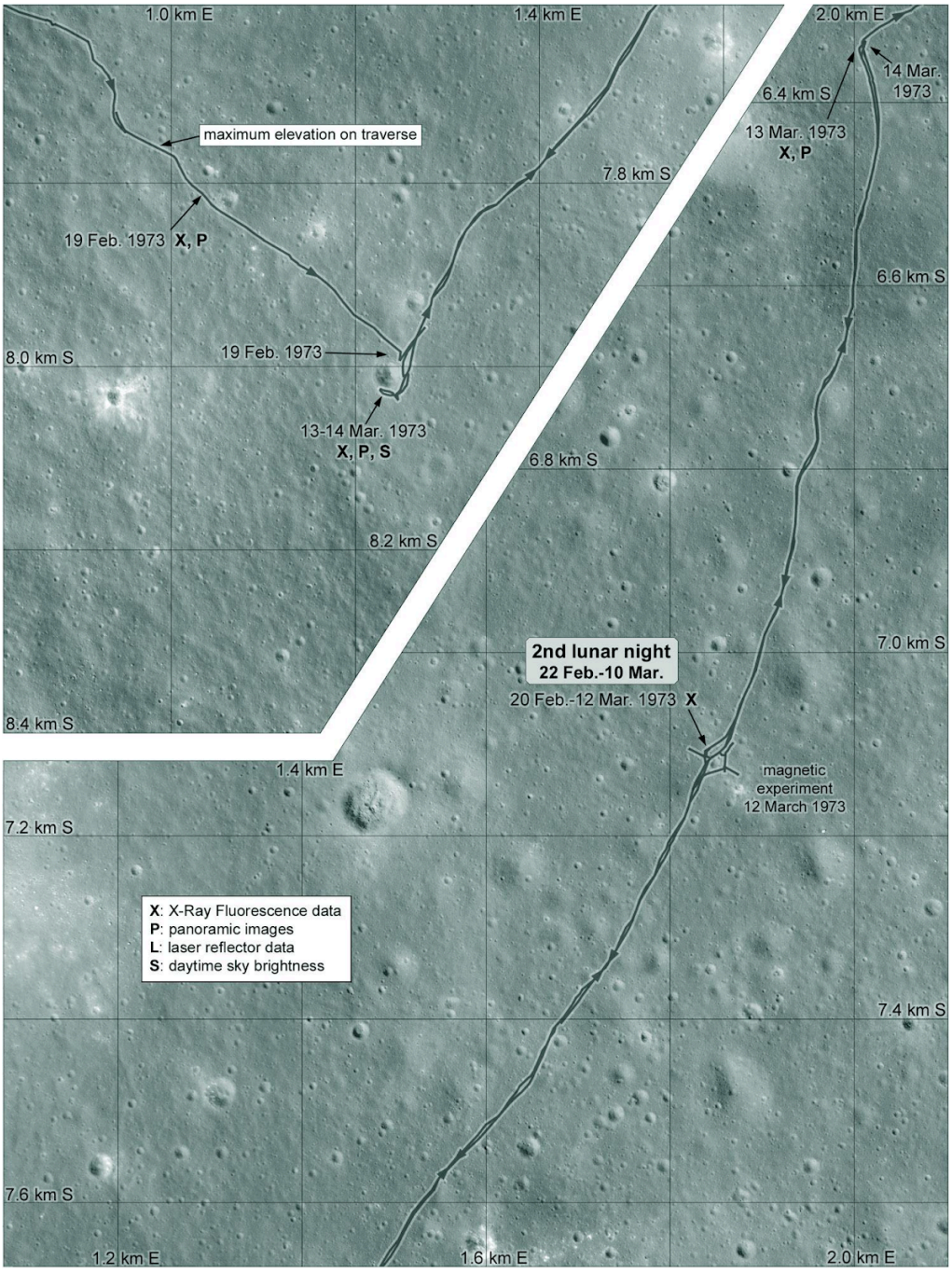


An image from the Lavochkin website which seems to show the Earth as a crescent (at left) and a sliver of the lunar landscape at right. This was labelled as a Luna 16 image but that must be wrong. There have been reports of a Lunokhod 2 image like this so this is probably its source.

April 16, 2025 - #maps #moon #luna21 #lunokhod2

We move on to the 5th map of the Lunokhod 2 route. A quick look today and more detail tomorrow as it is past my bedtime. The rover drove out of Margo crater and a bit further southeast, stopping beside a little crater on 19 February. On 20 February it drove 1 km northeast and stopped by another small crater for the 2nd lunar night. Early on lunar day 3 it made another cross-shaped 'special magnetometer experiment' around that crater. Then it drove on...

(Image on next page)



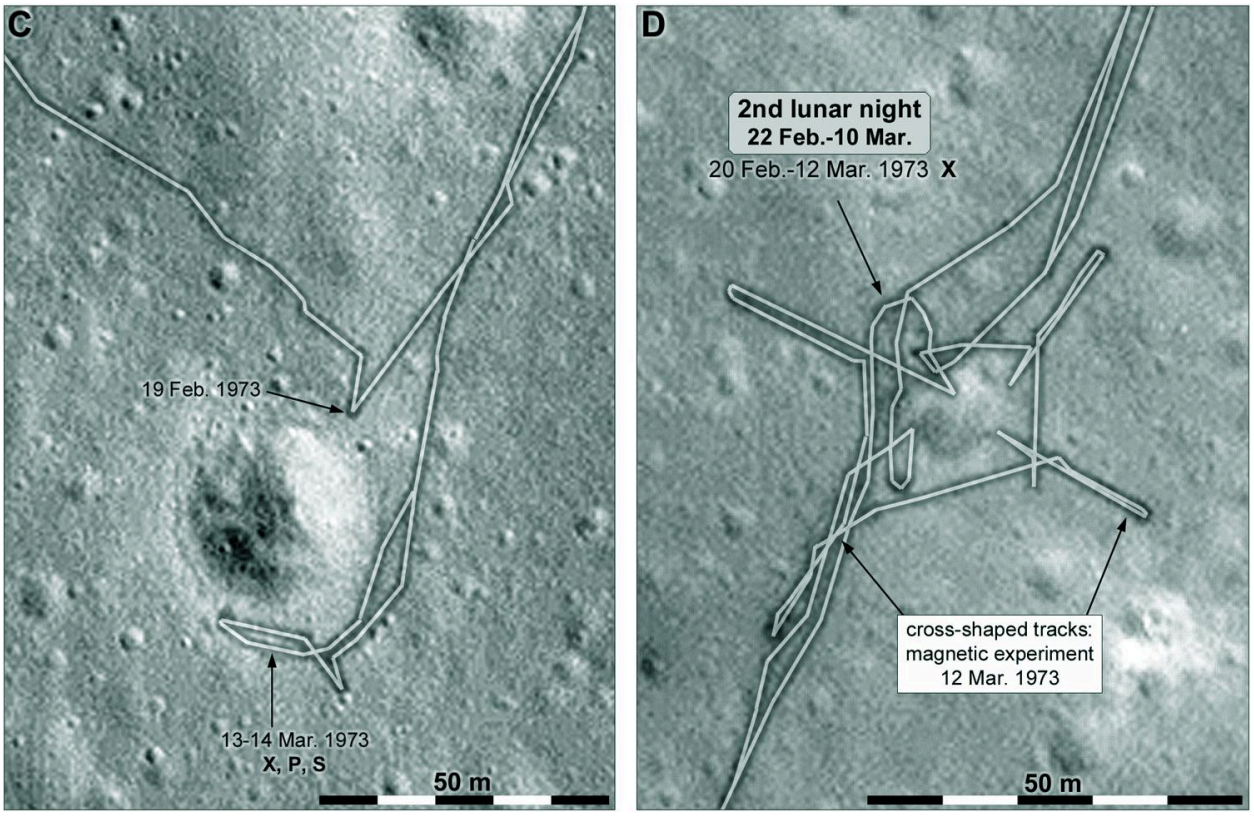
The 5th section of the Lunokhod 2 route map. The rover moved southeast after leaving Margo crater, then northeast and stopped for its 2nd night. The next morning saw another cross-shaped magnetic experiment, then a drive northeast. Then the rover drove rapidly right back along its tracks, turned and drove back again - making a triple traverse. The magnetometer was used along the path, and in fact during the whole mission, not just the special experiment areas.

April 16, 2025 - #moon #luna21 #lunokhod2

Lunokhod 2 drove on about 800 m north. On the next day it drove all the way back along its tracks to the southernmost point, turned and drove all the way back to the top right corner of the map. This made a triple traverse, useful for magnetometer data again and testing driving ability. We will look at some of this in more detail next.

April 17, 2025 - #maps #moon #luna21 #lunokhod2

Here are two maps of sites of interest from the last map. The first is the southernmost point of the traverse (and the south end of the triple traverse). The second is the cross-shaped 'special magnetic experiment' area. In the second map it's not necessarily easy to work out the exact path from the complex tracks, though I will be looking again at modern Russian mapping to clarify some details.

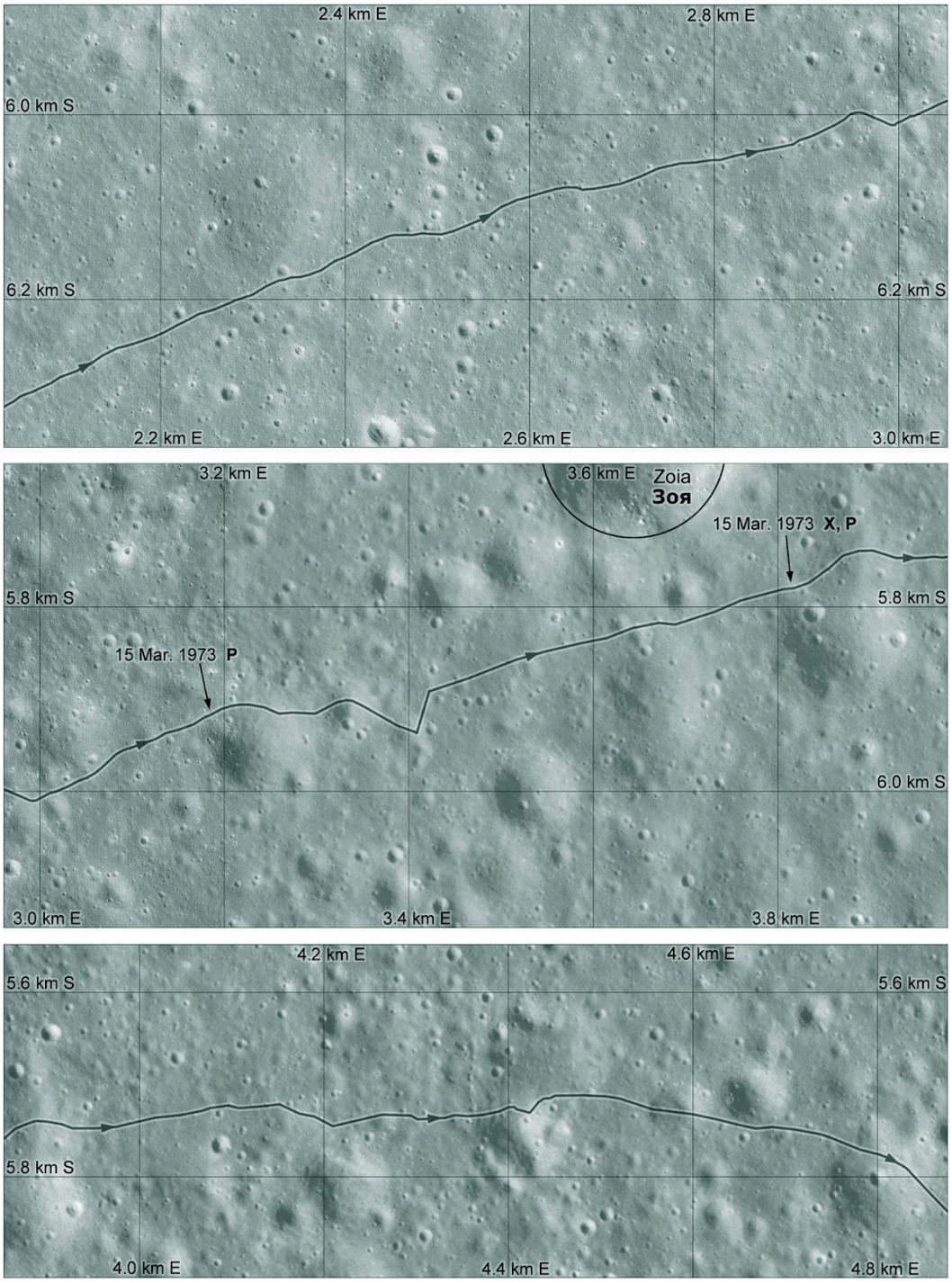


Maps of two areas visited by Lunokhod 2. At left is the south end of the triple traverse, and at right is the second night location with the cross-shaped tracks of another magnetic experiment, once again centred on a small crater.

April 18, 2025 - #maps #moon #luna21 #lunokhod2

We now commence a long, looooonnnggg trek to the east. Long in distance for a rover, anyway, but not long in time because the drivers put the pedal to the metal here. This map shows the beginning of this drive in 3 panels, each spanning 1000 m, so it is 3 km of driving done over 2 days. "Flagstaff Arizona, don't forget Winona" - good road trip music.

(Image on next page)

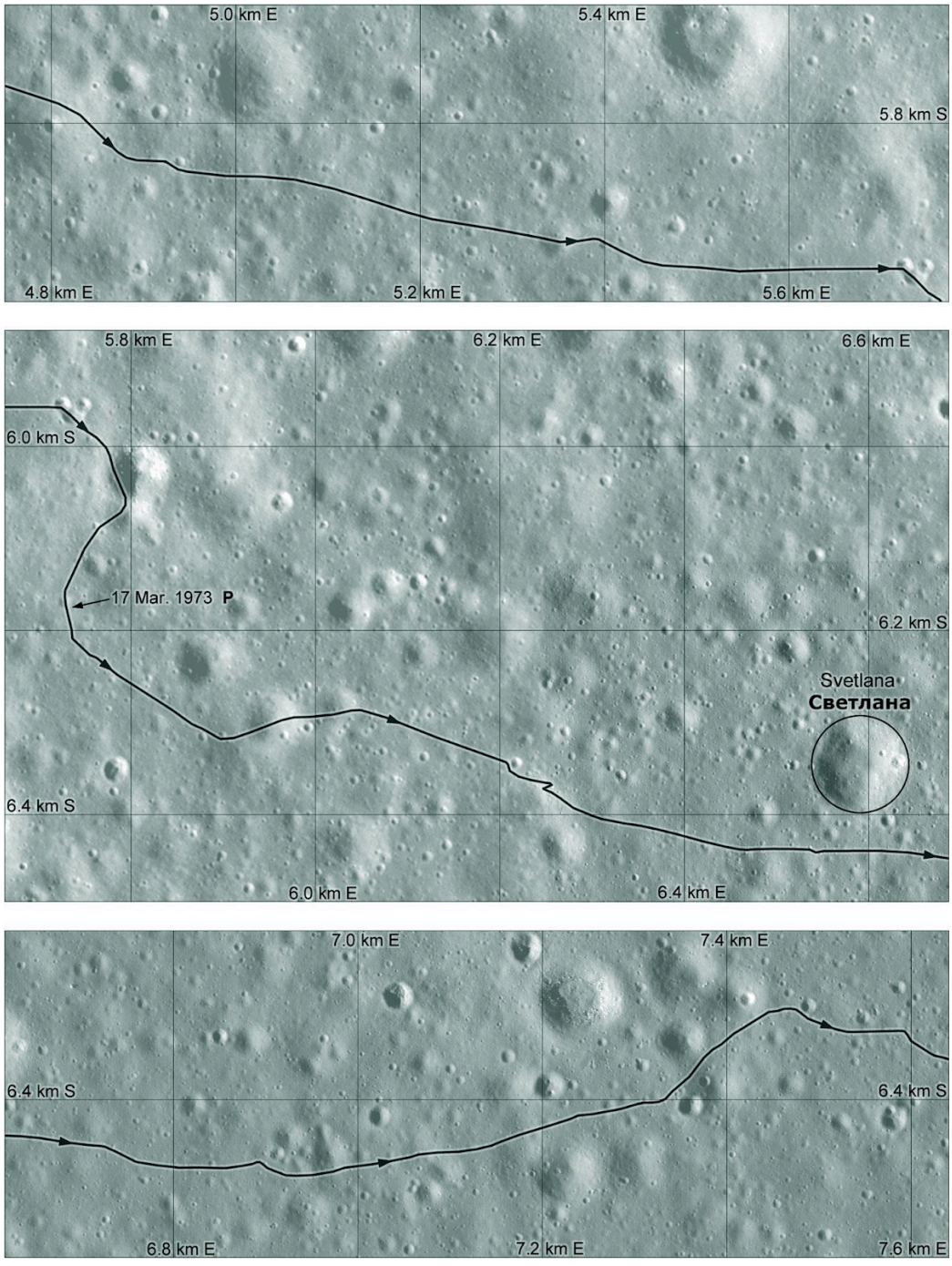


Map 7 of the Lunokhod 2 road trip, in 3 panels. Each one is 1000 m wide so it covers 3000 m of driving, almost due east, done over 2 days.

April 19, 2025 - #maps #moon #luna21 #lunokhod2

Our next Lunokhod 2 map section looks similar to the last one. Three panels give us another 3 km of driving. Several of these drives exceeded 2 km per day, particularly the longest drives of the mission on 17 March (2230 m) and 18 March (3130 m). We don't always know where the overnight stops were as the map only shows where measurements were made. With this map we are about half way through the traverse.

(Image on next page)



A map similar to the previous one, showing the Lunokhod 2 traverse east of the prevous map. Three panels, each representing an area 1000 m wide, cover 3 km of the journey. The rover moved between craters rapidly by modern rover standards, covering 2 km on several days and 3 km on 18 March 1973 (bottom panel and part of the next map).

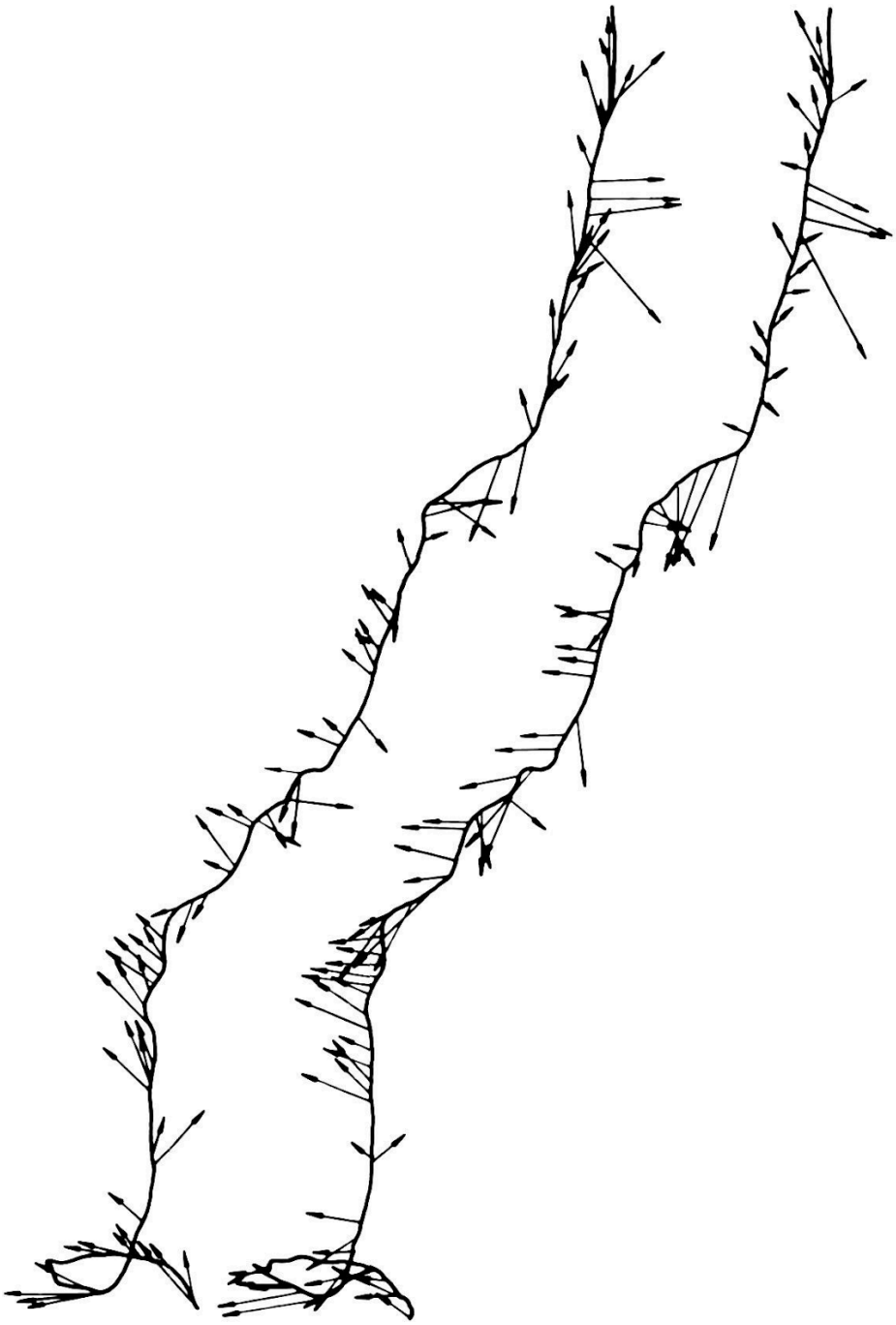
April 20, 2025 - #maps #moon #luna21 #lunokhod2

Lunokhod 2 used its magnetometer along most of the traverse, not just at the cross-shaped areas. This image shows the data as published in:

Dolginov, S.S. et al., 1977. Magnetic field in Le Monnier Bay according to data of Lunokhod 2. In The Soviet-American Conference on Cosmochemistry of the Moon and Planets, pt. 1.

The two lines show the route on my maps 3 and 4, with Margo crater at the south end. Arrows show the horizontal component of the field ....

(Image on next page)



A map of the Lunokhod 2 route corresponding roughly to my 3rd and 4th route map sections, with Margo crater at the bottom (the track has a recognizable loop in that crater). There are two versions of the rover track with small arrows depicting the horizontal component of the magnetic field at intervals. They show the map with and without considering the external field. Don't ask me what it means, I don't do this kind of work.

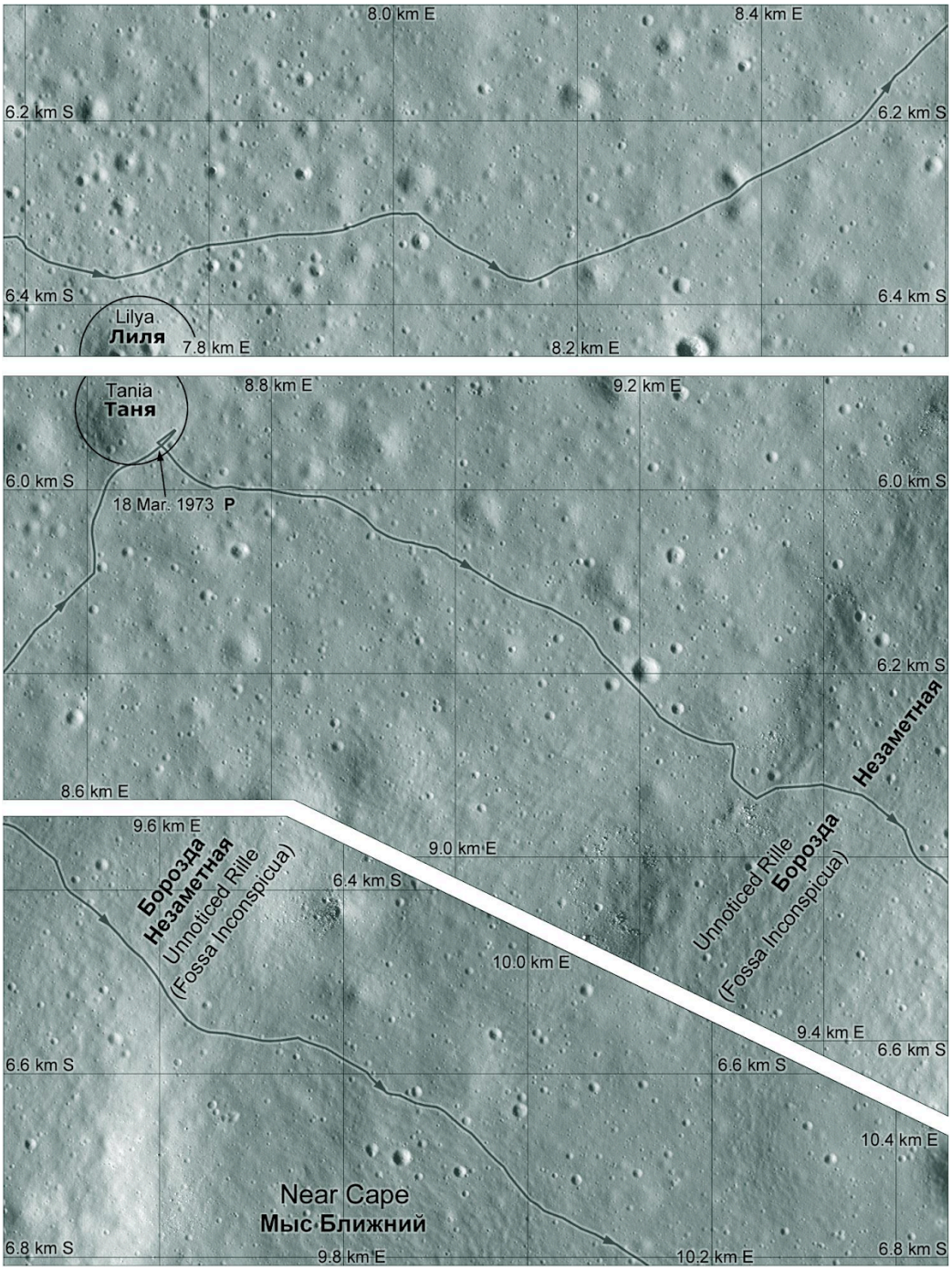
April 20, 2025 - #moon #luna21 #lunokhod2

... horizontal component of the field with and without considering the external field. This is not my kind of work so don't ask me what it means. Maps like this cover much of the route with the triple section in another paper by Dolginov. It would be nice to see the raw data but as far as I know it is buried in the State Library on big tapes. There is no 'planetary data system' to distribute it. Apollo ALSEP data was similarly lost until a recent effort to recover it.

April 21, 2025 - #amps #moon #luna21 #lunokhod2

This is the 8th map in this sequence of Lunokhod 2 route maps. Check back for an index to the maps and another with names of landscape features. Here we have another set of 3 panels covering another c. 3 km of distance but here with more deviation north and south. At one point the rover enters a crater but speedily backs up and exits again. Later it crosses a depression so shallow that it was seen from orbit but not noticed by the drivers.

(Image on next page)



The 8th map of the Lunokhod 2 traverse. Again there are 3 panels but the rover winds north and south as it travels generally to the east. At the right end of panel 2 and the left end of panel 3 it crosses a very shallow depression, visible in orbital images but so subdued that the drivers apparently did not even notice it.

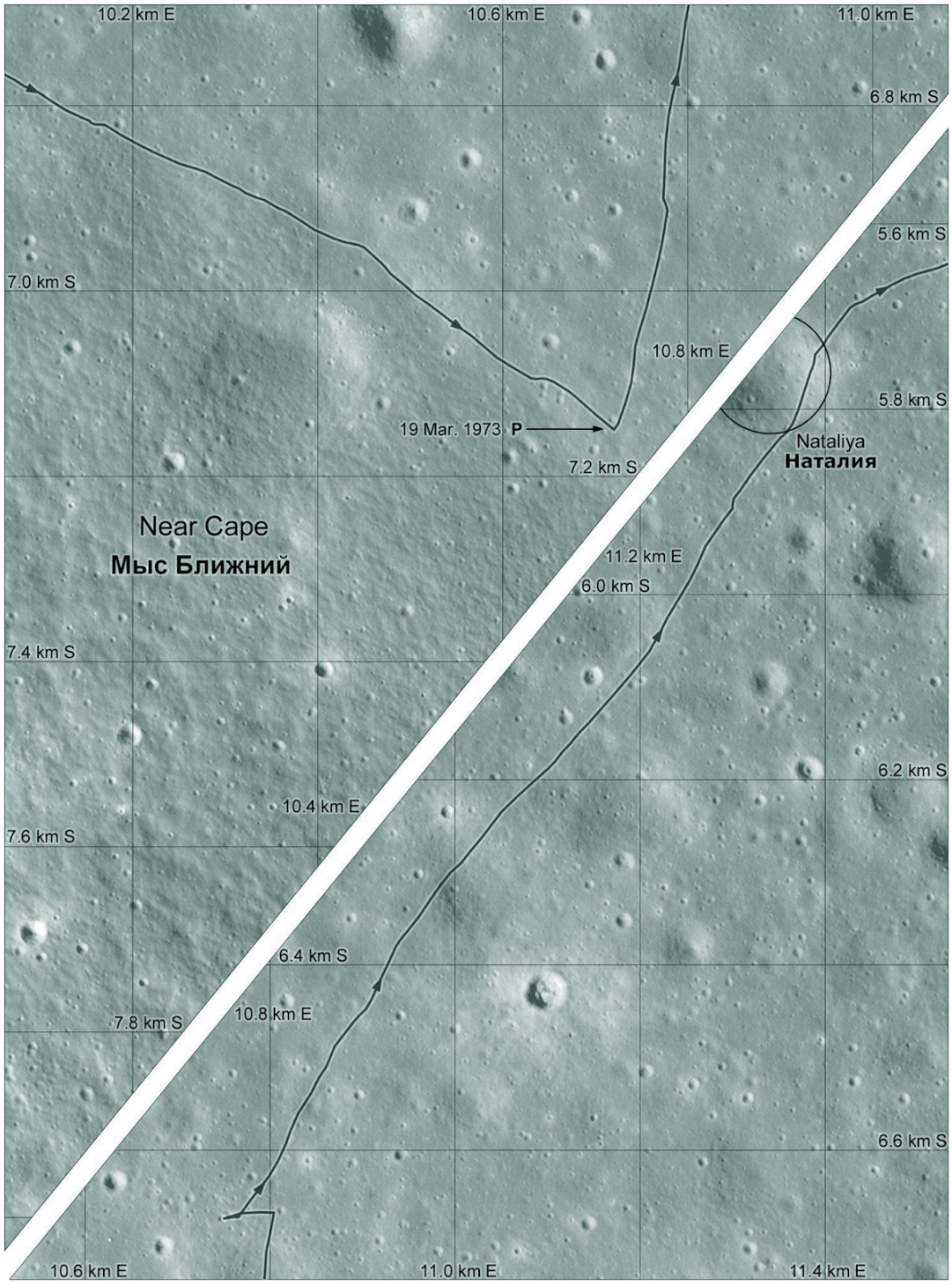
April 21, 2025 - #moon #luna21 #lunokhod2

There is a story that one day in the mission the rover drivers were so intent on what they were doing that they were suddenly surprised to lose all contact with Lunokhod 2. Only when they looked outside did they realize the Moon had set while they were working. This is a reminder that they did not have a global array of communication stations like the Deep Space Network. I don't know when that happened, but somewhere on this long fast drive east would be a good guess.

April 22, 2025 - #maps #moon #luna21 #lunokhod2

This is the 9th part of my Lunokhod 2 map. Sorry it's so broken up! - it is designed to fit on pages of a book or PDF document. The rover starts by driving southeast along the base of a hill (Near Cape), then turns north and continues northeast away from the hills. It drives through a crater called Nataliya, shallow enough that it is not much of an impediment to progress.

(Image on next page)



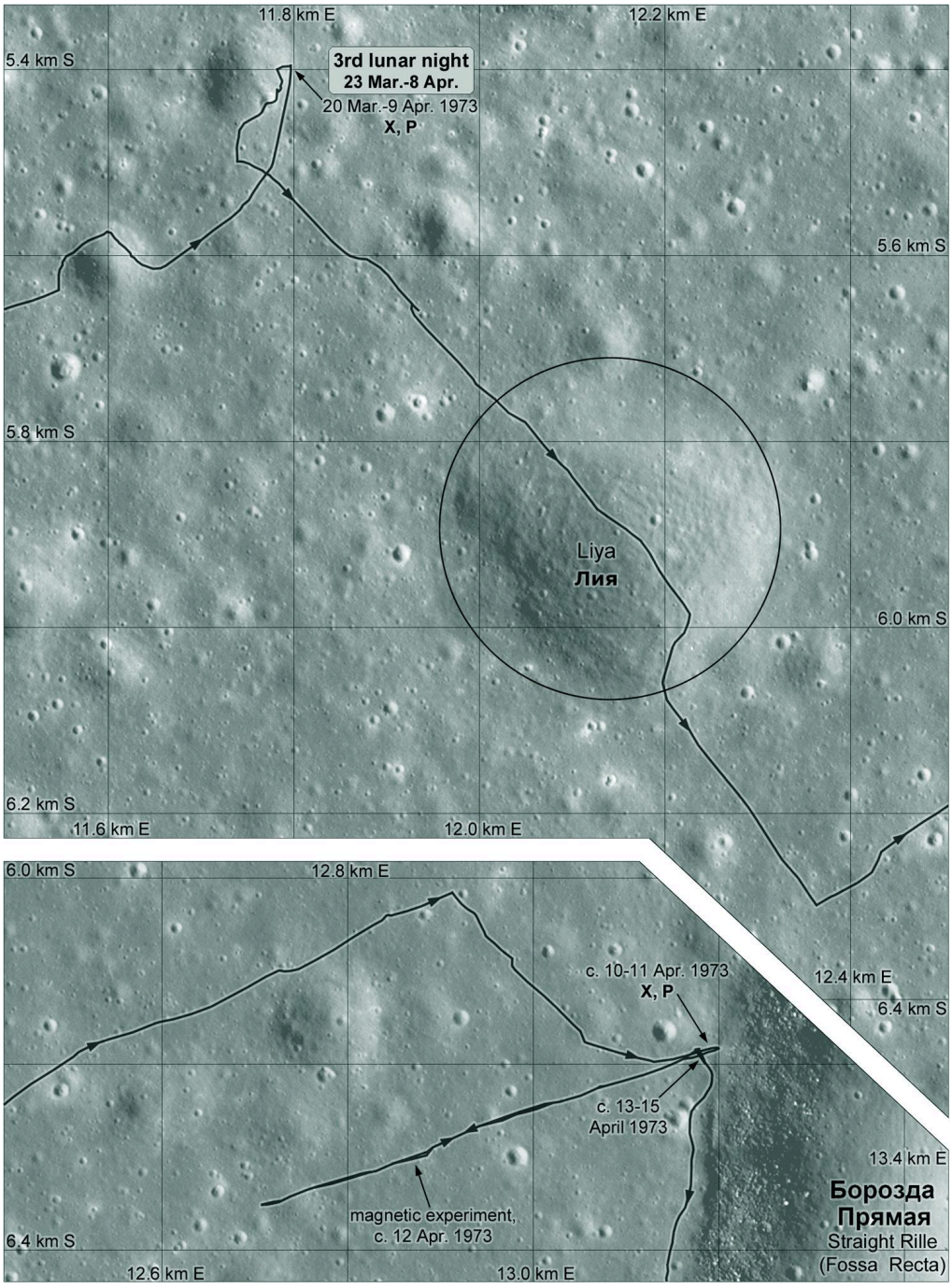
The 9th section of the Lunokhod 2 route map. There are two maps separated by a diagonal line. At left the rover drives along the base of a hill called Near Cape, the suddenly turns away and drives north. At right the path continues to the northeast and through a crater called Nataliya.

April 23, 2025 - #maps #moon #luna21 #lunokhod2

Lunokhod 2 continued its drive into this, the 10th part of the map, and we are now moving into the most interesting area, topographically. It is a terrible shame that full panoramic images could not be taken - the panoramic camera viewed only a narrow strip which hardly does justice to the dramatic scenery here.

At top left is the location of the 3rd lunar night. The rover drove 16 km in that lunar day.

(Image on next page)



The 10th section of the Lunokhod 2 map. This includes the 3rd lunar night location at top left, a drive to the southwest through a shallow 400 m crater, and then arrival at the edge of a linear trough called Straight Rille. A 'rille' is a valley, a German term from the 19th Century when German astronomers were the world's foremost lunar cartographers. Here the rover made a c. 500 m drive away from and back to the rille with the magnetometer operating, and sat out the lunar noon.

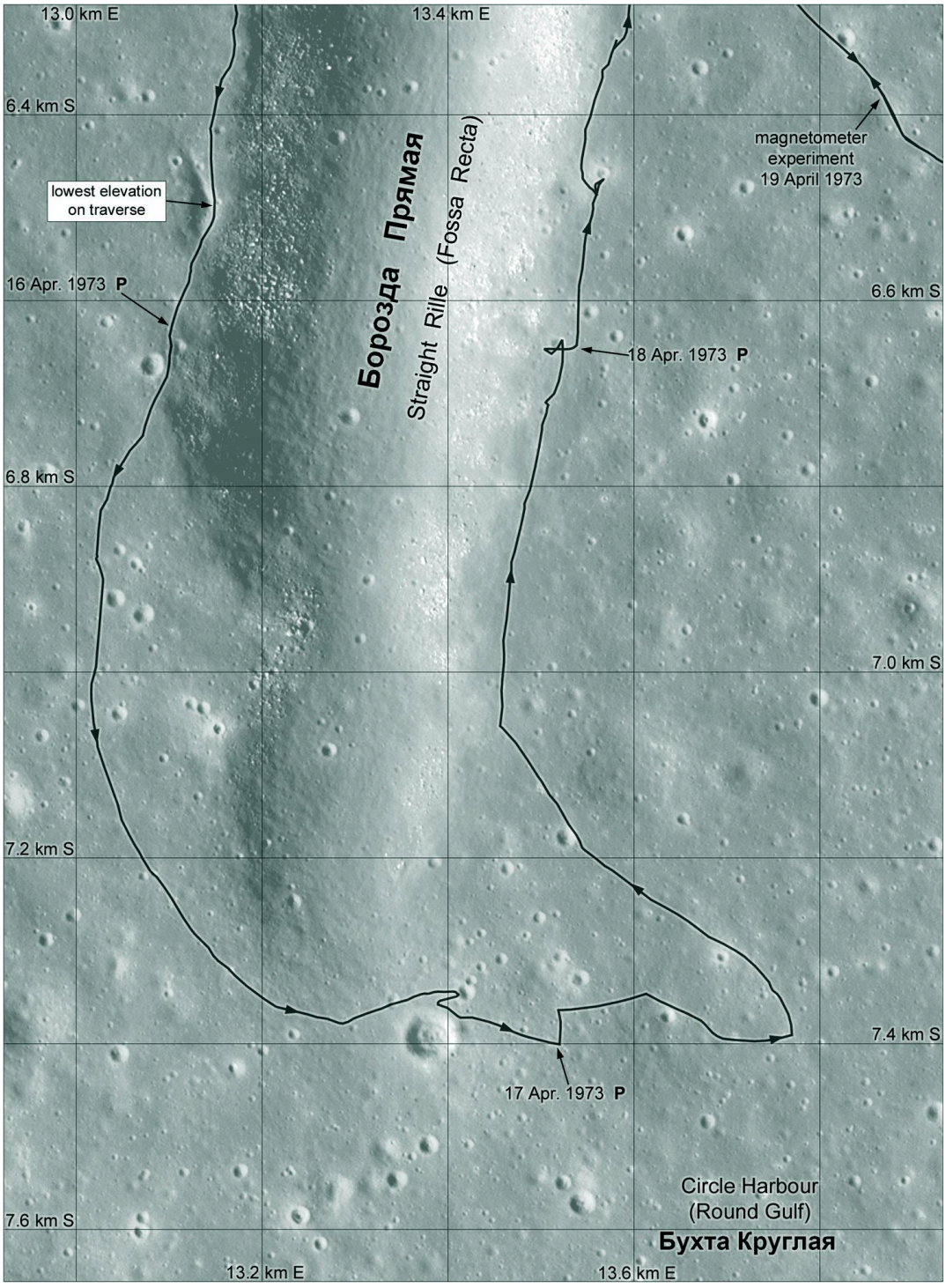
April 23, 2025 - #moon #luna21 #lunokhod2

Early in lunar day 4 Lunokhod 2 made a drive to the southwest through a shallow 400 m crater called Liya, and then arrived at the edge of a linear trough called Straight Rille. A 'rille' is a valley, a German term from the 19th Century when German astronomers were the world's foremost lunar cartographers. This was the site of another magnetic experiment, not around a crater this time but roughly perpendicular to the rille.

April 24, 2025 - #maps #moon #luna21 #lunokhod2

We are nearing the end of Lunokhod 2's traverse. In this 11th map of the set the rover drives south down the western edge of the trough, eastwards around its southern end, and back to the north again, all in a couple of days. At top right a bit of a second magnetometer excursion is visible, but we will see it all in the next map. In several places the rover stops at a small crater and backs away to bypass it.

(Image on next page)

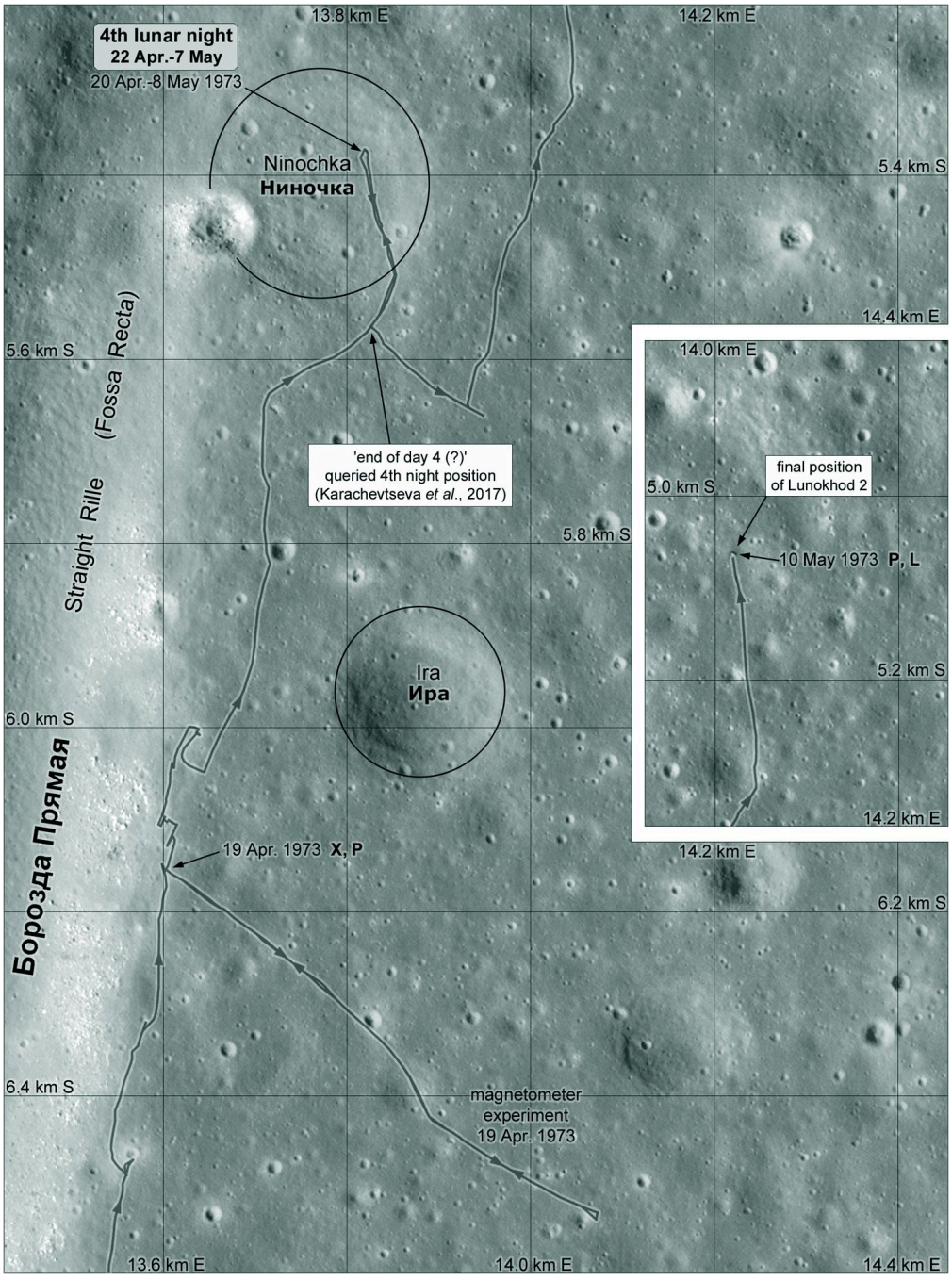


The 11th section of the Lunokhod 2 map. The map is dominated by the southern end of a 400 m wide trough. Lunokhod 2 drove from the top left corner, south along the edge of the trough, east around its base and north up the other side.

April 25, 2025 - #maps #moon #luna21 #lunokhod2

Finally we reach the last section of the Lunokhod 2 traverse map. The rover was driven northwards along the edge of the trough, pausing to do a magnetic back-and-forth experiment roughly symmetrical to the one on the other side. At the top of the main map Lunokhod 2 entered the very shallow Ninochka crater, and accidentally entered a small crater inside it. This is where the infamous 'dirt on the lid' event happened, and we will explore it in more detail later.

(Image on next page)



The 12th and last section of the Lunokhod 2 map. This one has the long straight trough or valley on its western (left) side. The rover was driven northwards along its rim. Then it made an excursion to the southeast and back for another magnetic experiment. Continuing northwards it entered a 200 m wide shallow crater, and while inside it, drove into a small steep-sided crater, Struggling to get out, it got dirt on its 'lid' which eventually ended the mission, as we will see later. A small inset map shows the final rover position north of that spot.

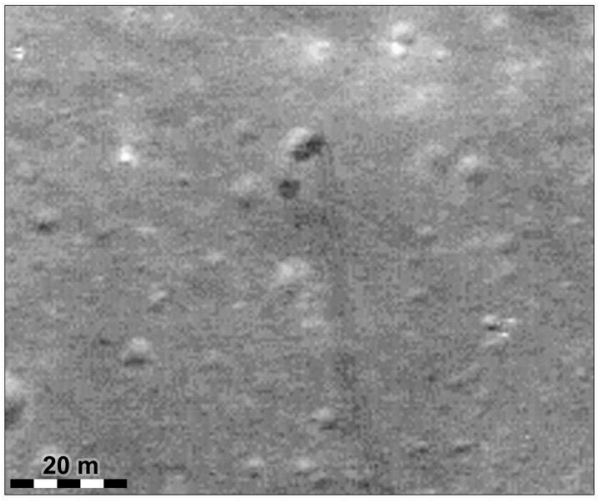
April 25, 2025 - #moon #luna21 #lunokhod2

There is some uncertainty about the exact position of the 4th night stop, and I may be revising this map later. On day 5 the rover drove further north again before overheating and stopping. The rover activities in this area were instrumental in setting me up for yet another clumsy mistake which got widespread attention. Oh yes, even LRO was not enough to stop me causing chaos... but more on that tomorrow.

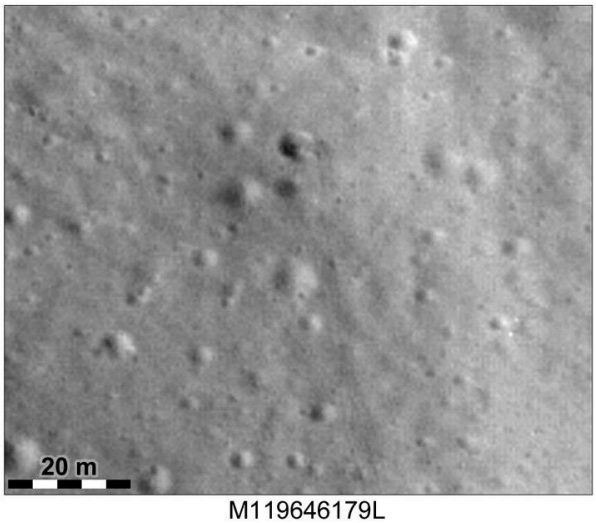
April 26, 2025 - #moon #luna21 #lunokhod2

This story is all about what happened to Lunokhod 2 on the floor of that crater Ninochka on the previous map. First we will look at what really happened, and we will get to the stupid bit later. Here are 5 different LRO NAC images of the location, chosen to have the best resolution available and different illumination. See how variable the track visibility is. We see tracks, craters and a prominent dark spot (though not prominent in every image)

(Image on next page)

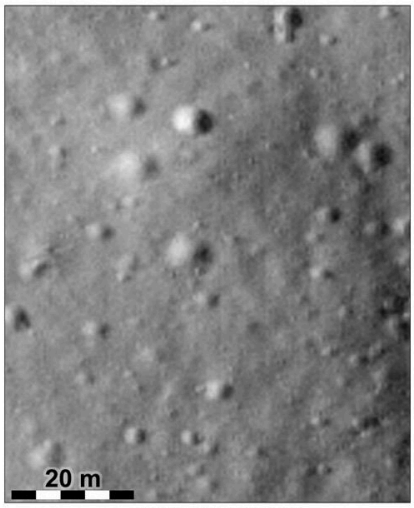


M109039075L

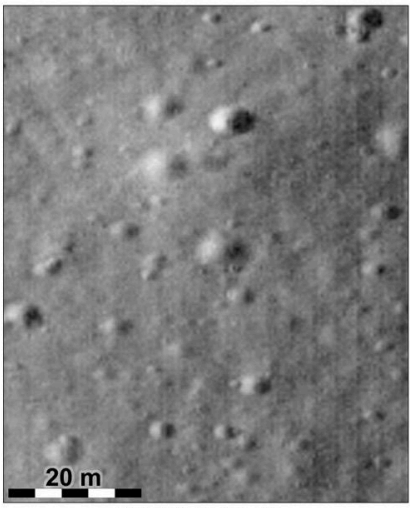


M119646179L

M139707174R



M177426582R

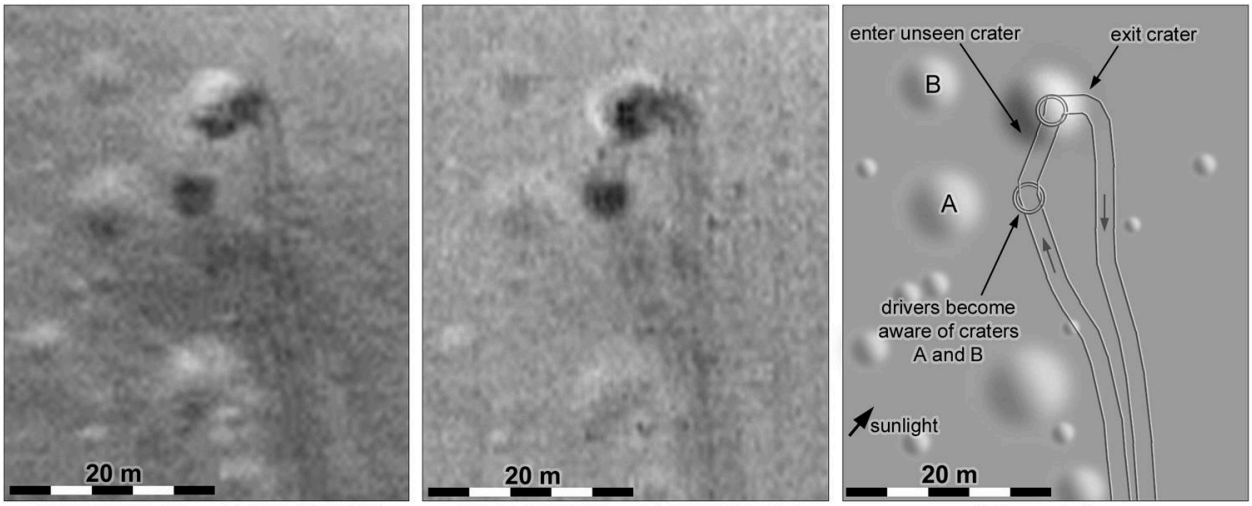


M177433351R

Five different images of the location where Lunokhod 2 had its accident, one that would eventually prove fatal. The same set of craters is visible, plus rover tracks and a dark spot, but track visibility is very variable depending on lighting.

April 26, 2025 - #maps #moon #luna21 #lunokhod2

How should we interpret these images? At left I use two images with similar lighting, merged to reduce noise and improve visibility of tracks. In the middle, two images with roughly opposite lighting (morning and afternoon) are merged to reduce the visibility of topography and emphasize albedo (i.e. tracks). They look similar which is encouraging. At right is my interpretation of events. We know they accidentally drove into a crater without seeing it. But how?



M109039075L + M139707174R M119646179L + M177433351R interpretation

Three images of he same area of Lunokhod 2 tracks are shown side by side. At left, two images with similar lighting are merged to reduce noise and improve visibility of tracks. In the middle, two images with roughly opposite lighting (morning and afternoon) are merged to subdue the visibility of topography and emphasize albedo (tracks). At right is my interpretation of events in this area.

April 26, 2025 - #moon #luna21 #lunokhod2

For years I assumed the dark spot was made by the rover wheels after leaving the crater, but that doesn't make sense. The crater was not seen, and the only way it would not be seen is if the rover is driving away from the sun (Apollo astronauts told us that). The accident happened in the late afternoon when the sun was in the southwest, so the rover was moving northeast. I think the rover was driving north and the drivers saw craters I call A and B on my map ...

April 26 2025 - #moon #luna21 #lunokhod2

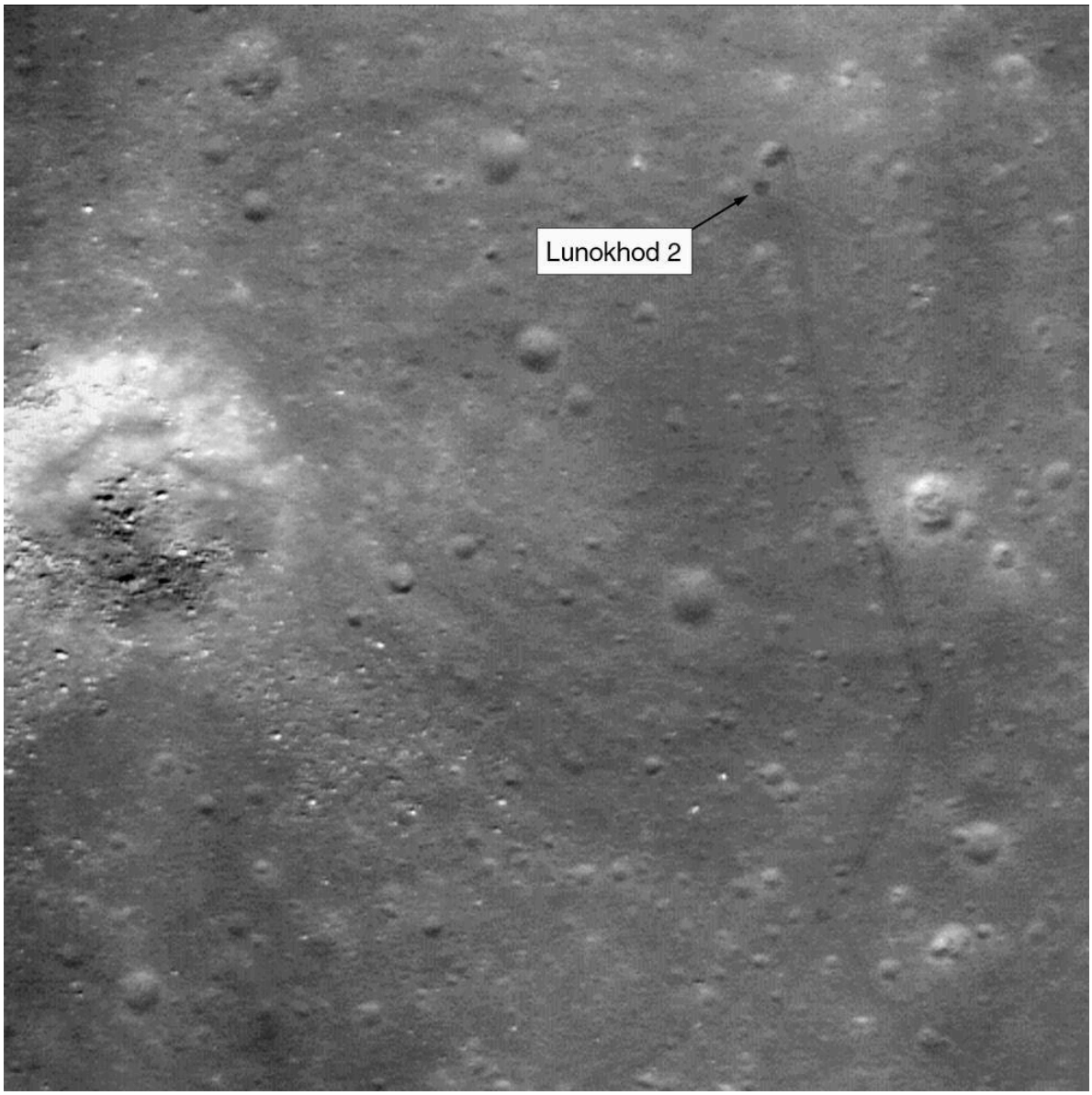
... They stop and turn around (making the dark spot) to find a way past A and B. The other crater looks like it should be easy to see but it's down-sun and was not noticed. Also they are only using their driving TV cameras - there are no panoramas here to guide us. So they find themselves in the crater and struggle to get out. They have done it before, it should be OK, but the lid hits the crater wall and the damage is done. They get out and stop somewhere nearby.

April 27, 2025 - #moon #luna21 #lunokhod2

Where did I barge into this story? We have to go back to March 2010. LRO has begun releasing images of landed spacecraft on the Moon. Remember the map I showed earlier, an old map of the Lunokhod 2 route with LRO images showing that the rover ended further north than previously thought. Now - these LRO Narrow Angle Camera images are big - 5000 by 50,000 pixels, and at the time my software was limited to 30,000 pixels so I always cropped images.

April 27, 2025 - #moon #luna21 #lunokhod2

So this particular image got cropped, but rather catastrophically I cropped off the actual rover. Luckily nobody noticed... until I spotted that dark marking and thought it might be the rover. I made this image. You can see the tracks, but in this view you can't really see the extra branch of the tracks running further east and north. I showed a few people, and the next thing I new it was being promoted by our university PR people.



An image of the Lunokhod 2 tracks and a dark spot misinterpreted as the rover itself. Reaklly it's a marking made by the wheels as the rover turned in place.

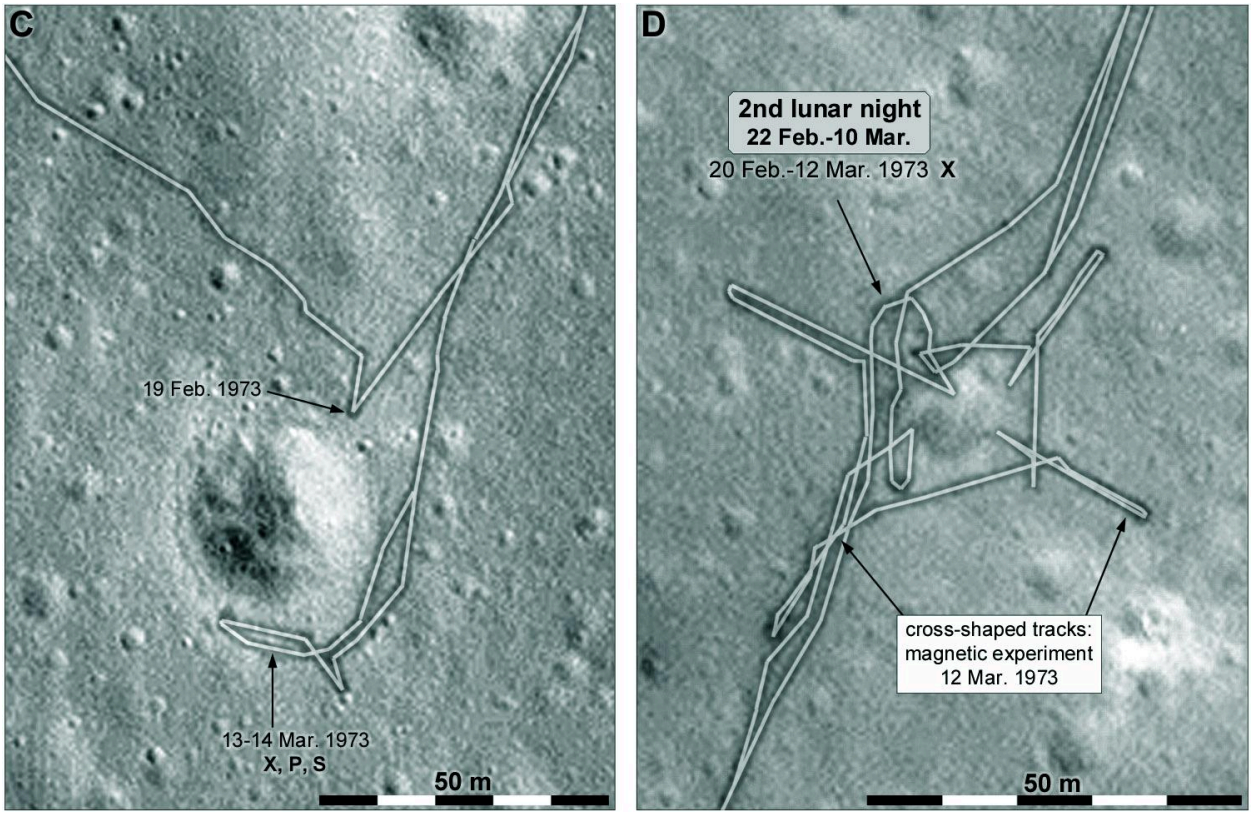
April 27, 2025 - #moon #luna21 #lunokhod2

And that would not be so bad except that they had to promote it as 'our prof found a rover that had been lost for decades'. Suddenly this was picked up by other media and everyone knew about it. Obviously, VERY quickly, the correct story emerged and I had to deal with it. The next time I saw Sasha Basilevsky I apologised profusely, but he was very polite and forgiving about it. Memo to self - don't be stupid.

Tomorrow: back to reality.

April 28, 2025 - #maps #moon #luna21 #lunokhod2

Here are two detailed maps of small parts of the Lunokhod 2 drive, this time from the 2nd lunar day, with the cross-shaped magnetic experiment tracks early in lunar day 3. The actual night position is a bit uncertain. It's great to have these wonderful images now, but the quest for something better never ends. Now it's 'we need 5 cm resolution to see details of the lander'. Oh, yes - and for geology.

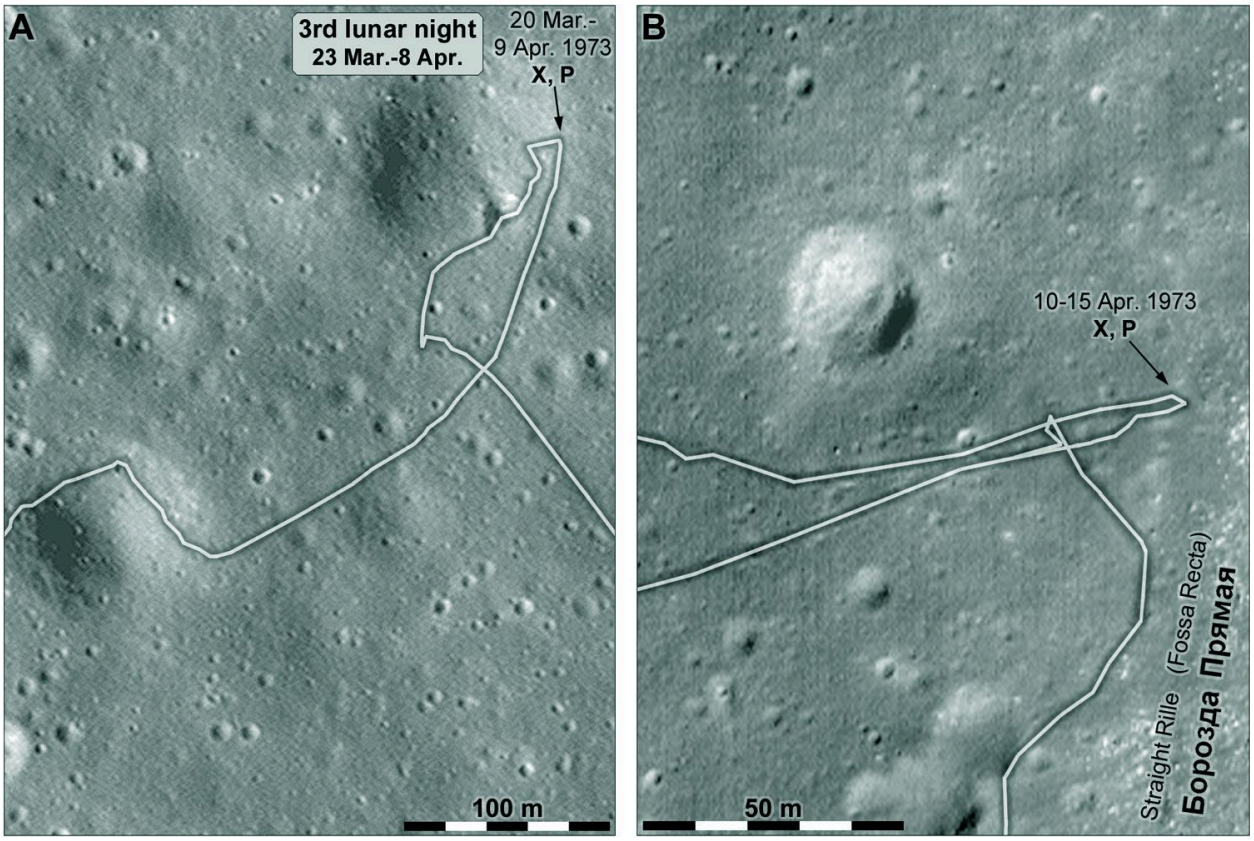


Two maps of places along the Lunokhod 2 drive during lunar day 2, including the lunar night 2 position and the cross-shaped tracks left during the magnetometer experiment early on day 3.

April 28, 2025 - #maps #moon #luna21 #lunokhod2

And 2 more maps like this. Here we see the third night location and the place where the rover arrived at the edge of Straight Rille, the long north-south trough.

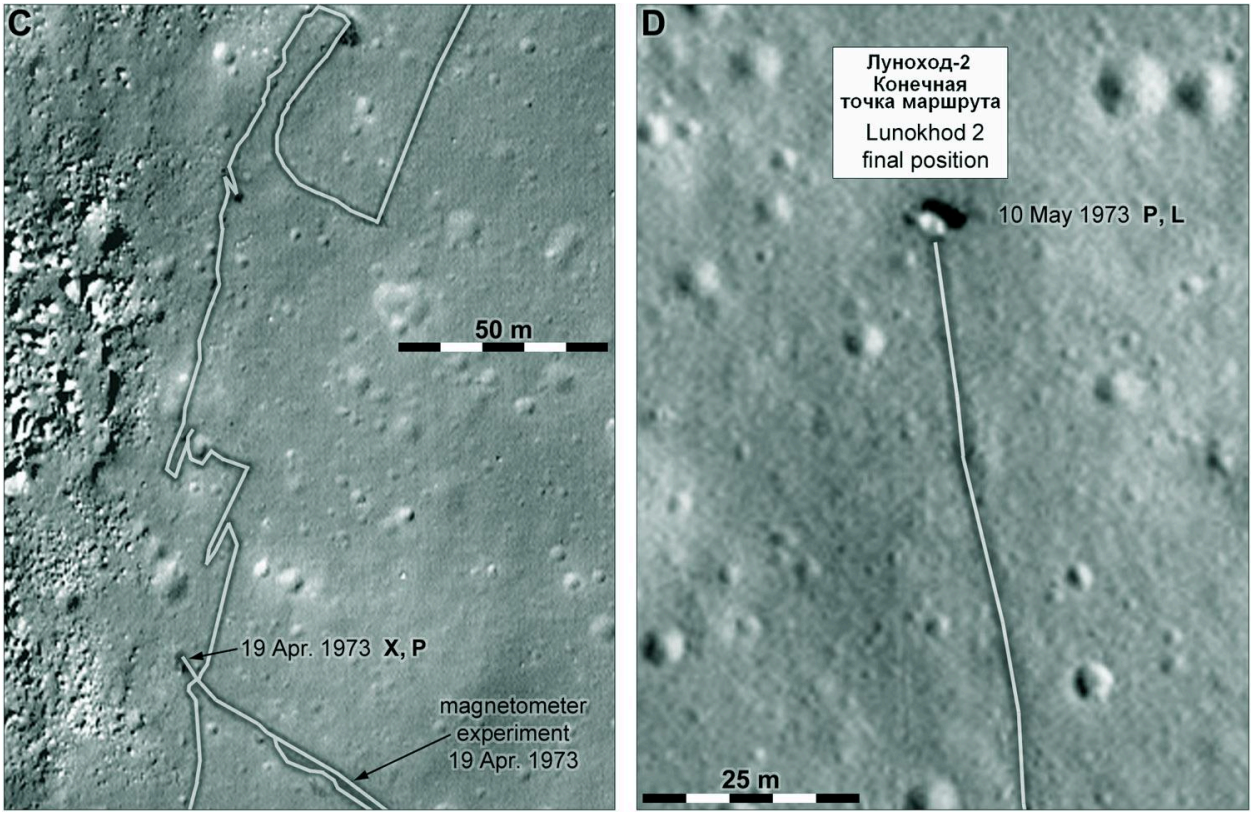
We will have two more maps like these tomorrow.



Two more detailed maps of places along the Lunokhod 2 traverse: the 3rd night position and the arrival at the edge of the north-south trough 'Straight Rille"

April 29, 2025 - #maps #moon #luna21 #lunokhod2

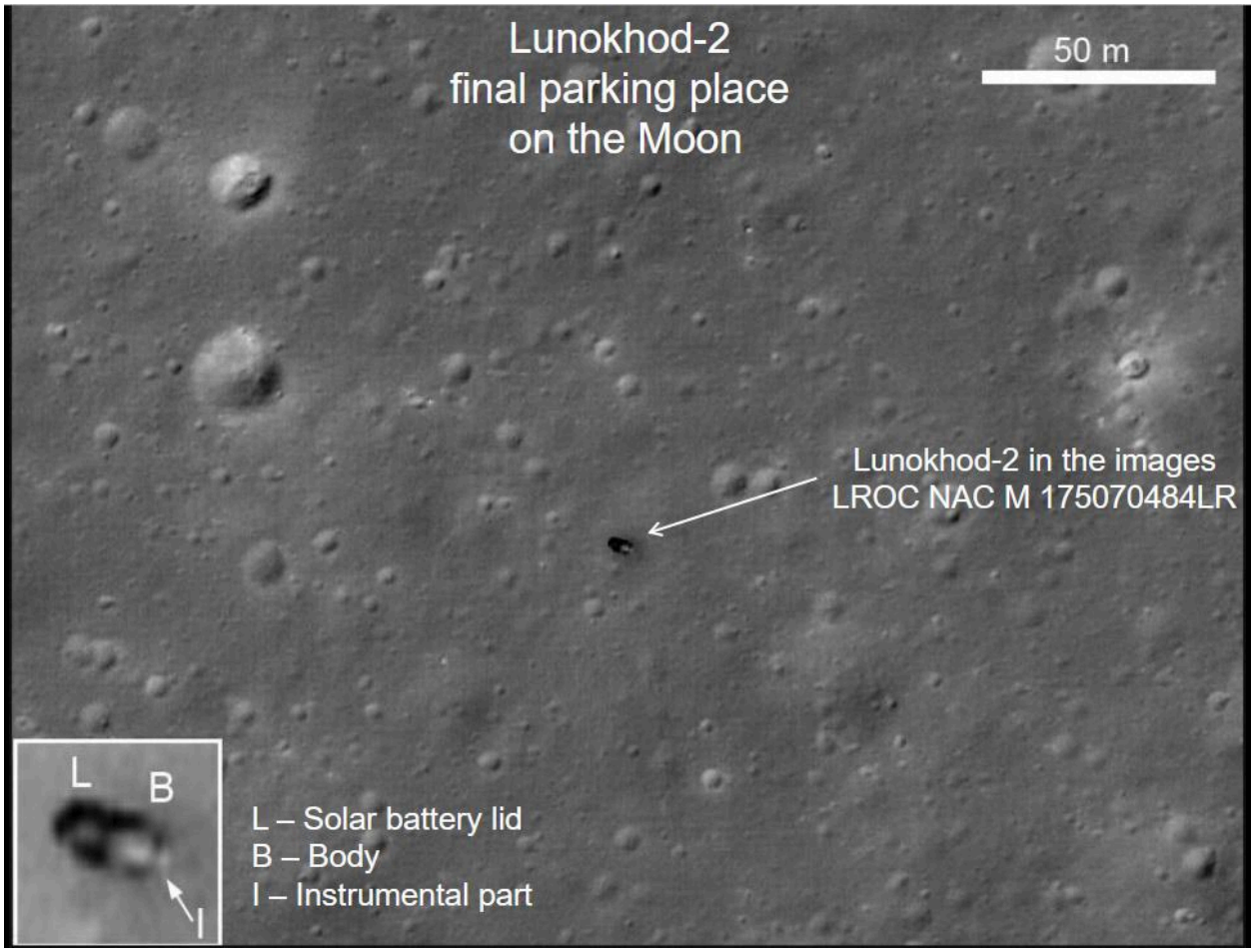
These are the final close-ups of this sequence of Lunokhod 2 maps. At left, a complex bit of driving along the edge of the trough. Some of the maneuvers may be for making stereoscopic pairs of panoramas showing the opposite side of the trough. At right, the last drive and final rover position. It seems the end was sudden and did not leave time for the laser reflector to be pointed at Earth. Its reflections are very weak.



Two detailed maps of parts of the Lunokhod 2 traverse. Left: a complex path along the side of the trough, maybe designed for stereo imaging of the far side of the trough. Right: the last drive and final position of the rover.

April 29, 2025 - #moon #luna21 #lunokhod2

Here is another look at the parked Lunokhod 2 rover, a slide from the presentation I linked to earlier in this thread. It shows the assumed orientation of the rover, though it's a bit of a puzzle still. I talked to the laser team, who are having trouble understanding how they get any reflection at all from the reflector in that orientation - it is part of the instrument section at the front (right end) of the rover.



A slide from a presentation by Sasha Basilevsky about Lunokhod 2 (linked to earlier in this thread). It shows the orientation of the rover with its science instruments at right.

April 29, 2025 - #moon #luna21 #lunokhod2

While we are talking about puzzles, here's another. At points marked 'S' on the maps a measurement of sky brightness was reported. Here's the citation:

Severny, A. B et al., 1975. The measurements of sky brightness on Lunokhod-2. The Moon v. 14, pp. 123-128.

They measured in visible and UV, both day and night. The UV sky was a bit brighter than expected, but the visible light sky was 'off-scale' bright and still quite bright after sunset…

April 29, 2025 - #moon #luna21 #lunokhod2

Their conclusion: the lunar daytime sky is too bright for useful astronomy. Night would be OK. This is attributed to dust lofted electrostatically or by impacts, and scattering sunlight.

This might seem counterintuitive. Surveyor and Apollo observations show some apparent effects of dust but the LADEE orbiter did not find much. Maybe the new Firefly images will help. Was there contamination of the Lunokhod instrument? We don't know.

April 30, 2025 - #moon #luna21 #lunokhod2

Early in our Lunokhod 2 sequence i gave a link to the Lunokhod 2 panoramas. Here is one of them:

https://www.planetology.ru/panoramas/images/big/lunokhod2_c/L2_D03_S05_P14m.jpg

Day 3, session 5, pan 14... it was taken at the south end of the triple traverse on 13 or 14 March 1973. One of my closeup maps shows that location with visible tracks around a crater. The crater is visible in this image. Across the crater are the day 2 tracks made on 19 February. My image here is a reprojection to show the tracks better.

A panorama from Lunokhod 2 projected very roughly into a geometry which shows rover tracks in a way that makes comparison with a map easier. This was at the south end of the triple traverse on 13 or 14 March 1973.

April 30, 2025 - #moon #luna21 #lunokhod2

And with that I think we will close our examination of Lunokhod 2, a remarkable mission in many ways. This was only the second time any vehicle had been driven remotely on another world (the first being Lunokhod 1), and I would rank them and the sample return missions as the greatest achievements of the Soviet Union in lunar exploration, on a par with their Venus results and far beyond what they accomplished at Mars.

Tomorrow... another orbiter.

May 1, 2025 - #moon #luna22

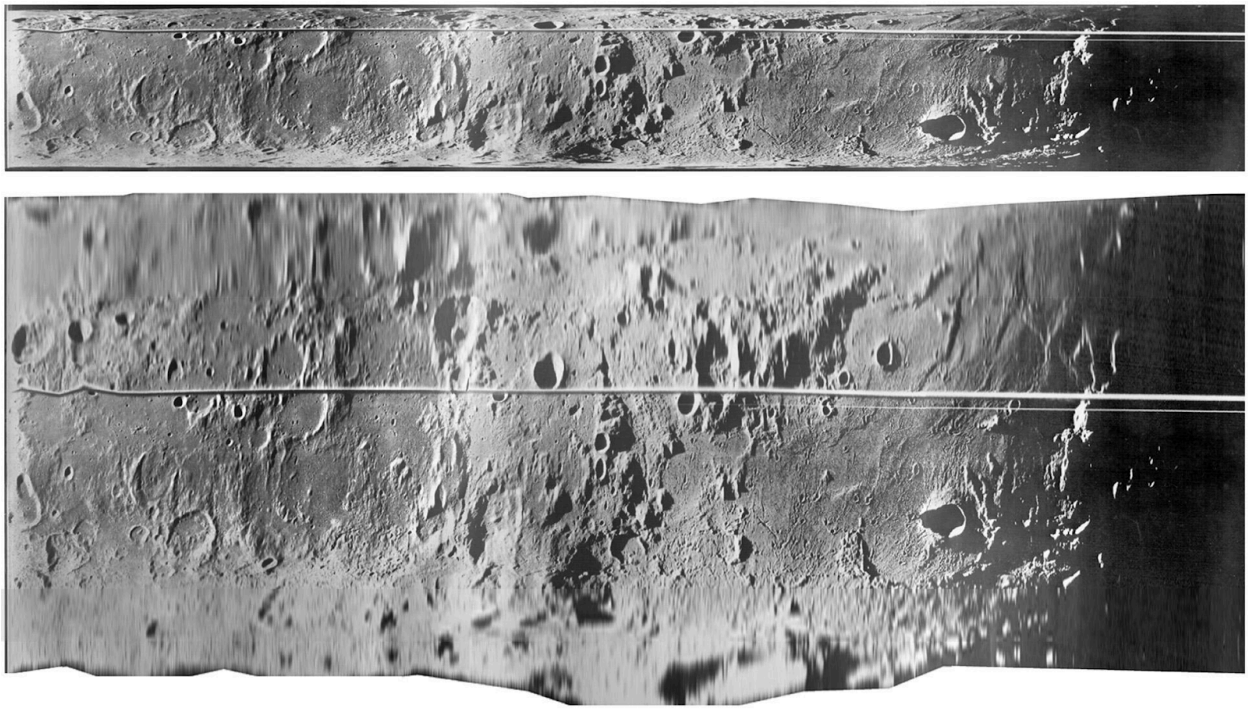
We move on to Luna 22, which was an orbiter similar to Luna 19. It was adapted from the design of the Lunokhod landing stage and rover, omitting landing legs, wheels and so on and adding various instruments and engineering tests. A basic description is given here:

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1974-037A

There was not a lot to say about Luna 19 but Luna 22 will keep us busy for a few days. We will see images, radar altimetry and bistatic radar data.

May 1, 2025 - #moon #luna22

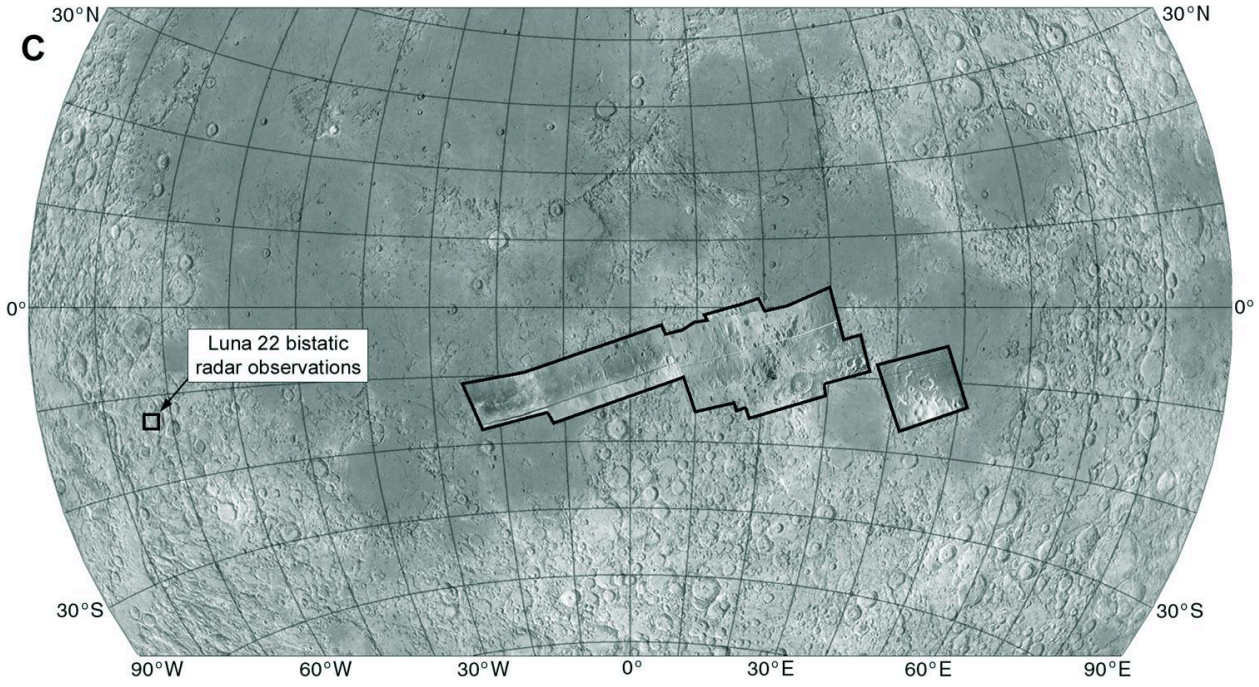
Let's look at the images first. They were produced by a scanner which scanned a line from horizon to horizon, successive lines being displaced by orbital motion. This image shows an example, with the raw scan above and a roughly projected version below, attempting to remove foreshortening towards the horizon. The area is in highlands south of Mare Tranquillitatis with Sinus Asperitatis at right. The line is an antenna or other object in the scanner field of view.



Two images from the Soviet Union's orbiter Luna 22. The top image is the original scanner strip, made by a camera which scanned a line from horizon to horizon (top to bottom). Lines were offset along track by orbital motion. Below it is a version of the same image which is projected to try to remove foreshortening near the horizon.

May 2, 2025 - #maps #moon #luna22

How many Luna 22 images were there? We don't know. On the NSSDCA page for the mission (linked yesterday) there is a statement about what they have: "Panorama 1 consists of three sections and panorama 2 consists of five sections". When I was at the Sternberg State Astronomical Institute, Vladislav Shevchenko showed me what are probably the same negatives. If all published images are mapped we see what may be one section from a third 'panorama' or swath.



A map of the lunar nearside showing the coverage of all known Luna 22 images. They form a strip just south of the equator. The pattern suggests they were taken over 3 separate orbits.

May 2, 2025 - #moon #luna22

Actually there must be other panoramas merged into the overlapping area. Don Mitchell also has Luna 22 images here:

http://mentallandscape.com/C_CatalogMoon.htm

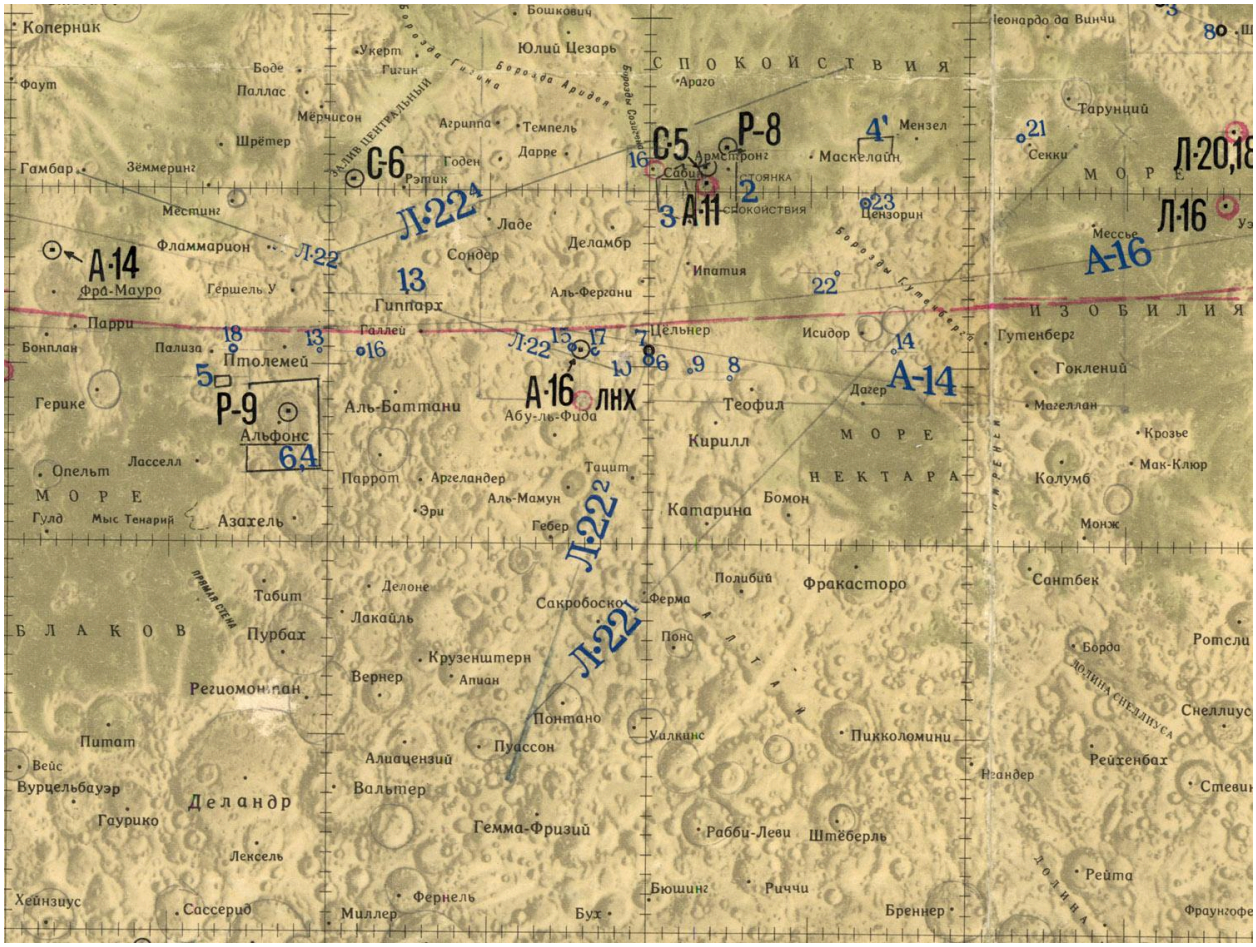
(near the bottom of the page) but they don't add any more to the map.

As with Luna 19, these images are not useful for studying the Moon and we can only make sense of them as tests of cameras designed for Mars or other places. Scanning imagers were flown on Mars 4 and 5.

May 3, 2025 - #maps #moon #luna22

I scanned this map at MIIGAiK in Moscow in 2001. It had been annotated with landing sites and other information (C-5 is Surveyor 5, P-8 is Ranger 8). The L-22 lines are altimetry tracks but 2 of them end about 30 deg. south. The orbit inclination would not allow that. Then my hosts found an obscure paper:

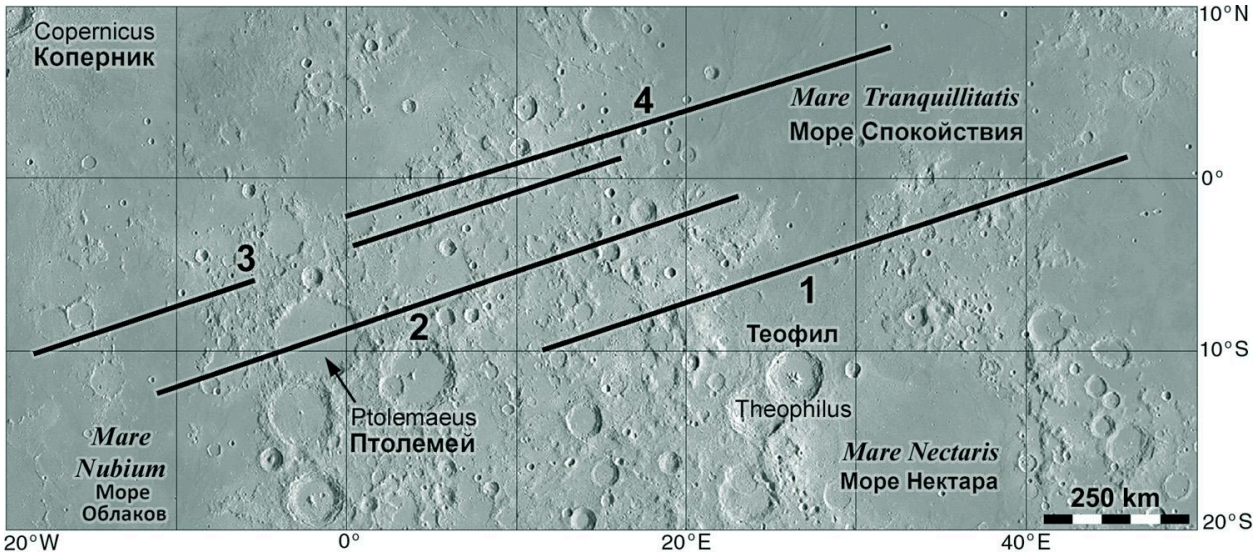
Tyuflin, Y. C. et al., 1976. Nekotorie resultat radioprofilirovaniya s avtomaticheskoi stantsii Luna-22. Kartografirovanie Lune i Planet, pp. 54-58. MIIGAiK, Moscow.



A map scanned in Moscow and annotated with landing sites and other information. The lines labelled L-22 represent Luna 22 altimetry tracks but, oddly, they are not correctly placed.

May 3, 2025 - #maps #moon #luna22

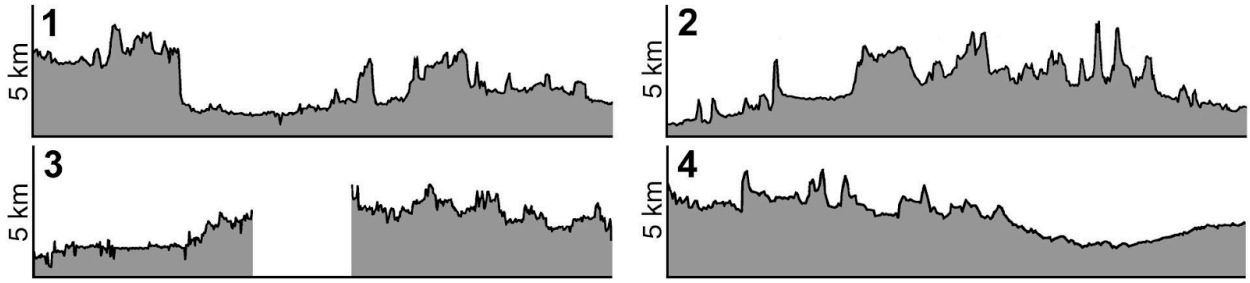
The paper cleared it up - some end-points of lines had been mis-plotted, not just in latitude but also confusing east and west longitude. The paper allowed me to draw the lines correctly. They match the pattern of images too, as you would expect. Only these tracks were made, again testing for planetary use. And we actually have the altimetry - which we will see tomorrow.



Correctly positioned altimetry tracks for Luna 22. They follow the pattern of images as would be expected.

May 4, 2025 - #moon #luna22

These are Luna 22 radar altimetry plots from that old Soviet-era publication. The vertical scale is shown, the same for each track. The plots match real features so we know they are correctly placed - number 2 crosses the large flat-floored crater Ptolemaeus, number 1 crosses Sinus Asperitatis and suddenly rises as it meets highlands to the west. Apollo altimetry was more extensive but did not cover this area (not until Clementine did we get our our first global topographic map).

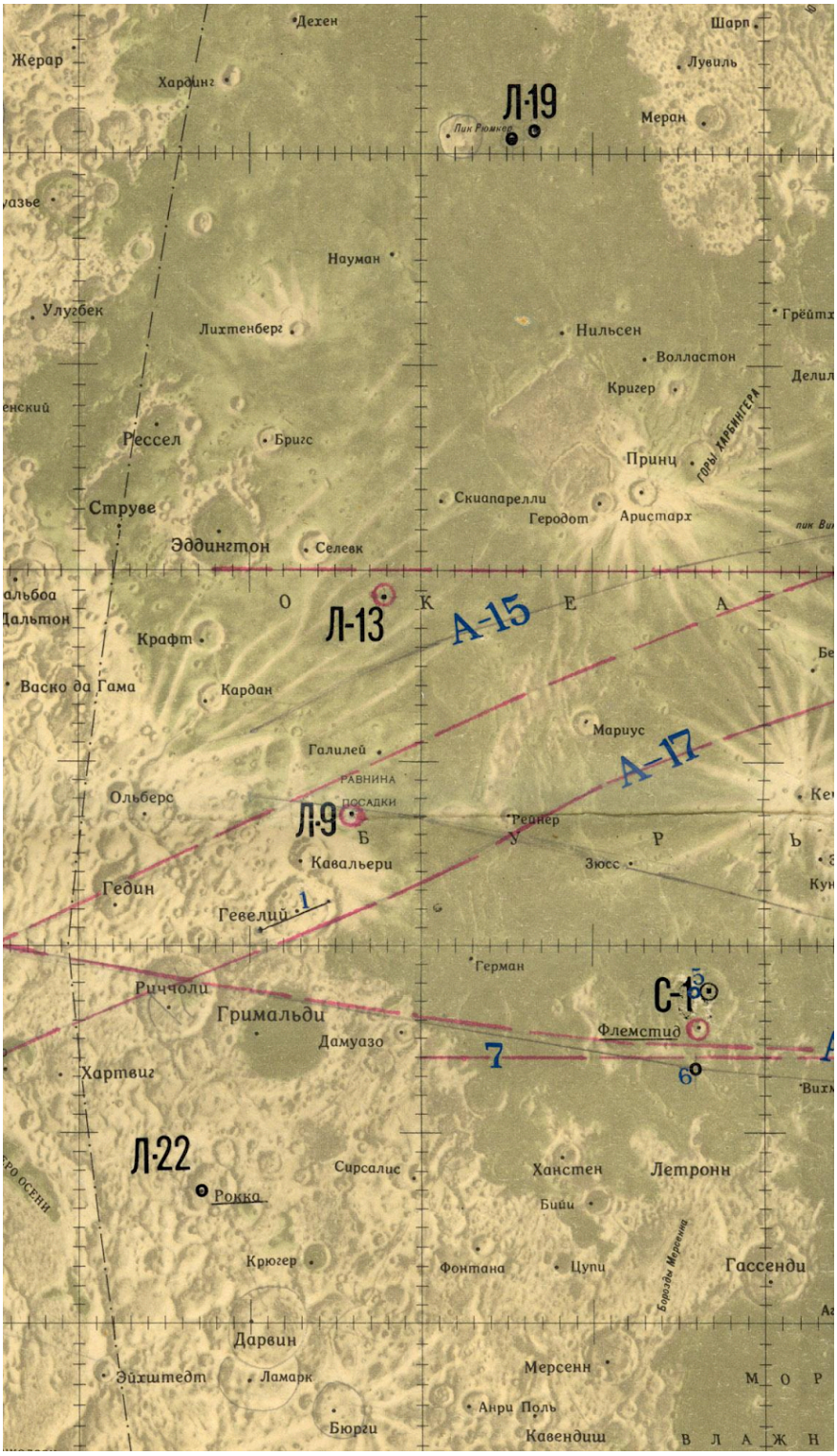


Four plots of radar altimetry from Luna 22, following tracks shown on yesterday';s map. The tracks are about 1000 km long and show 3 or 4 km of relief (greatly exaggerated here), including visible craters and other topographic features clearly seen on the map.

May 4, 2025 - #moon #luna22

Here is another section of that Russian map I saw at MIIGAiK. The dots marked L-19 and L-22 are the important points here. At the time I didn't know what they were. Now I know they were radar observations made using the altimeters. I mentioned the Luna 19 points earlier - they are actually 2 contiguous tracks of radar reflectivity data. For Luna 22 we get actual bistatic radar images - we will see them tomorrow but don't hold your breath until then.

(Image on next page)



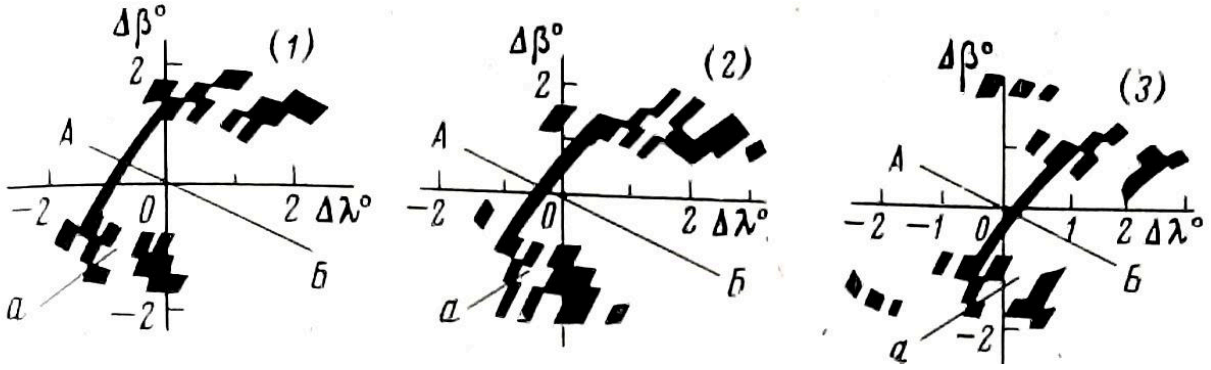
Part of the same Soviet-era map shown a few posts ago, indicating two points labelled L-19 and L-22 (actually the Luna 19 location was two points close together). They are sites of radar data from those two missions.

May 5, 2025 - #moon #luna22

I will look at the Luna 22 bistatic radar observation in more detail than it probably deserves because it is so little known. It was made at a crater called Rocca, involving 3 observations as the orbiter passed overhead. Here is the citation:
Zaitsev, A. L. et al. 1977. Bistatic radar surveillance of the moon, using a modulated signal. Radiotekhnika i Elektronika, v. 22, Oct. 1977, p. 2097-2104.
A friend helped me find it in the Lenin Library.

May 5, 2025 - #moon #luna22

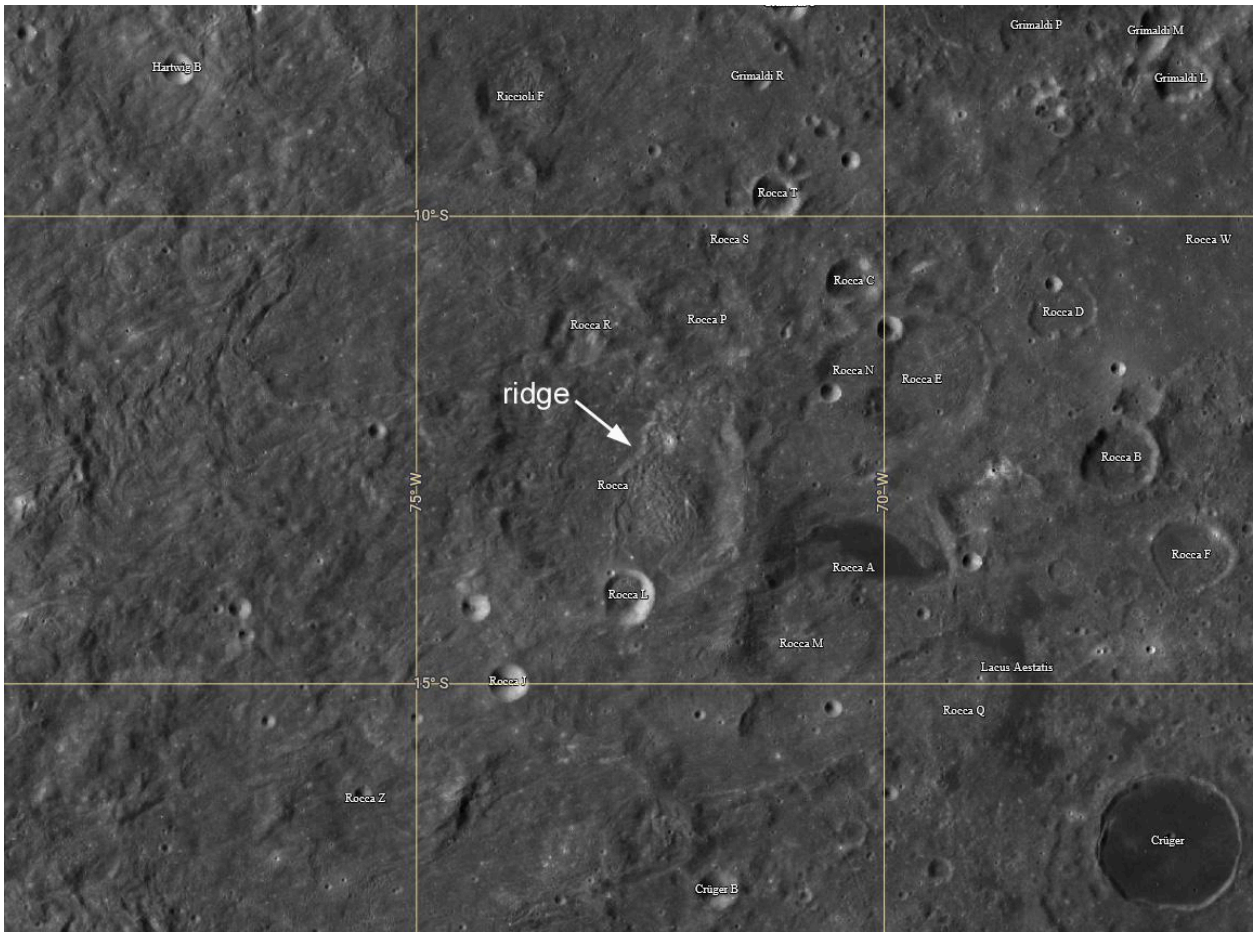
This is what the 'pictures' look like. The black marks are bright reflections. The pattern drifts across a grid fixed to the spacecraft as Luna 22 passes over the crater. A-B is an axis of symmetry and the image is north-south ambiguous across it. You can't tell if a specific reflection comes from north of the line or south of it. What can we do with this? Let's look at the Rocca crater area.



Three radar images of a crater called Rocca made by Luna 22. Black markings are bright reflections. The images show real features but they are north-south ambiguous.

May 5, 2025 - #moon #luna22

Here is Rocca, a c. 60 km diameter crater at 13 south, 72 west, mantled by Orientale ejecta. A ridge crosses its floor where Orientale ejecta has piled up against the downrange crater wall. A fresh smaller crater sits on Rocca's southern rim. The straight line in the radar image is that ridge, and strong reflections at the south end are from the rocky ejecta of the smaller crater. I made a composite of all 3 radar images to overlay on the crater…



Rocca crater seen in Quickmap. Note especially the ridge crossing its floor and a smaller sharp, fresh crater on its southern rim.

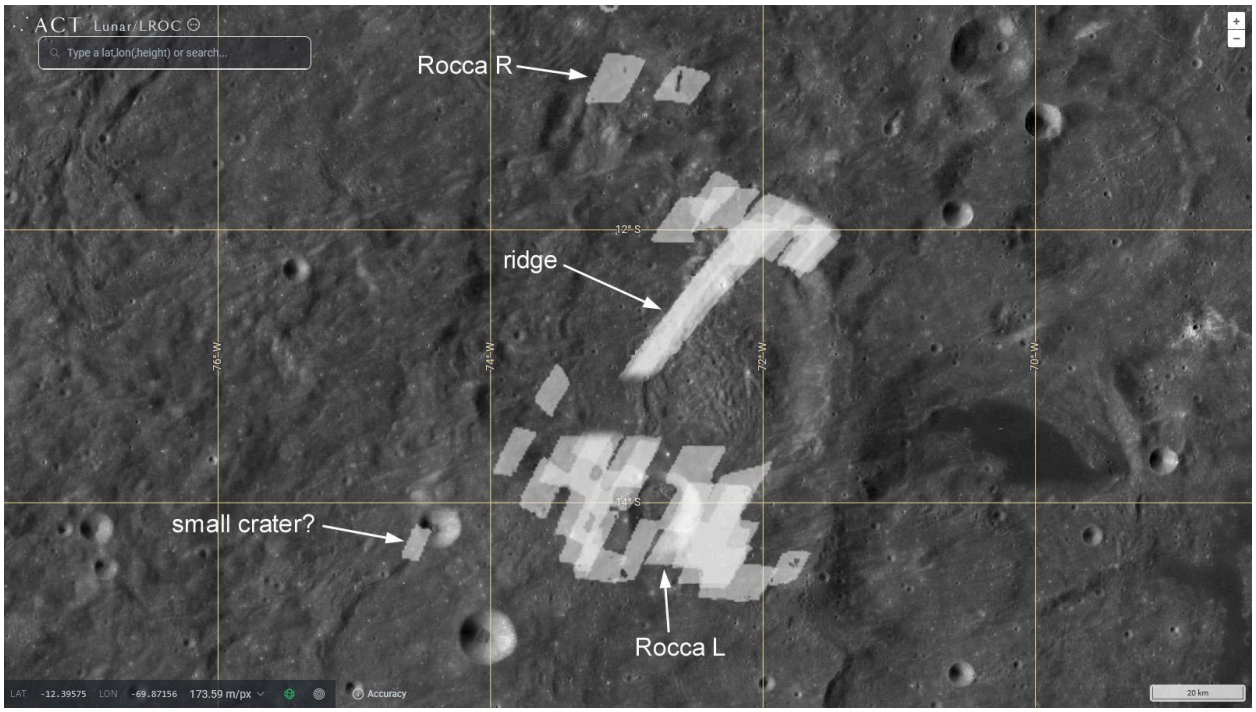
May 5, 2025 - #moon #luna22

(My interpretations here are from the Russian paper). If the bright reflection at the bottom is that crater ejecta, we can remove its ambiguous 'echo' from the top (next post). Some reflections at upper left may be from the north wall of Rocca R so their echoes can be removed at bottom left. One bright spot at lower left might be from a small fresh crater, so it is retained but removed at top left. It's a bit ad hoc but the best we can do.

A composite of the 3 Luna 22 radar images is laid over the image of Rocca crater. The geometry is only approximate. The line is that ridge, bright spots at the bottom are the rocky ejecta of the small crater.

May 5, 2025 - #moon #luna22

This is the image with some of that ambiguity clumsily removed. It's not just images, we also get surface roughness estimates. But is it useful? The interesting thing that comes from this is that a year after Luna 22 did this, the method was used at Venus by Venera 9 and 10 (more famous for their surface images), where it was the only way to get such details of the surface. Again, these lunar orbiters were testing methods for planetary exploration.



A rough attempt to remove ambiguity in that radar image from Luna 22, as described in the main post previous to this. This method was used to explore Venus in later years.

May 6, 2025 - #moon #luna23

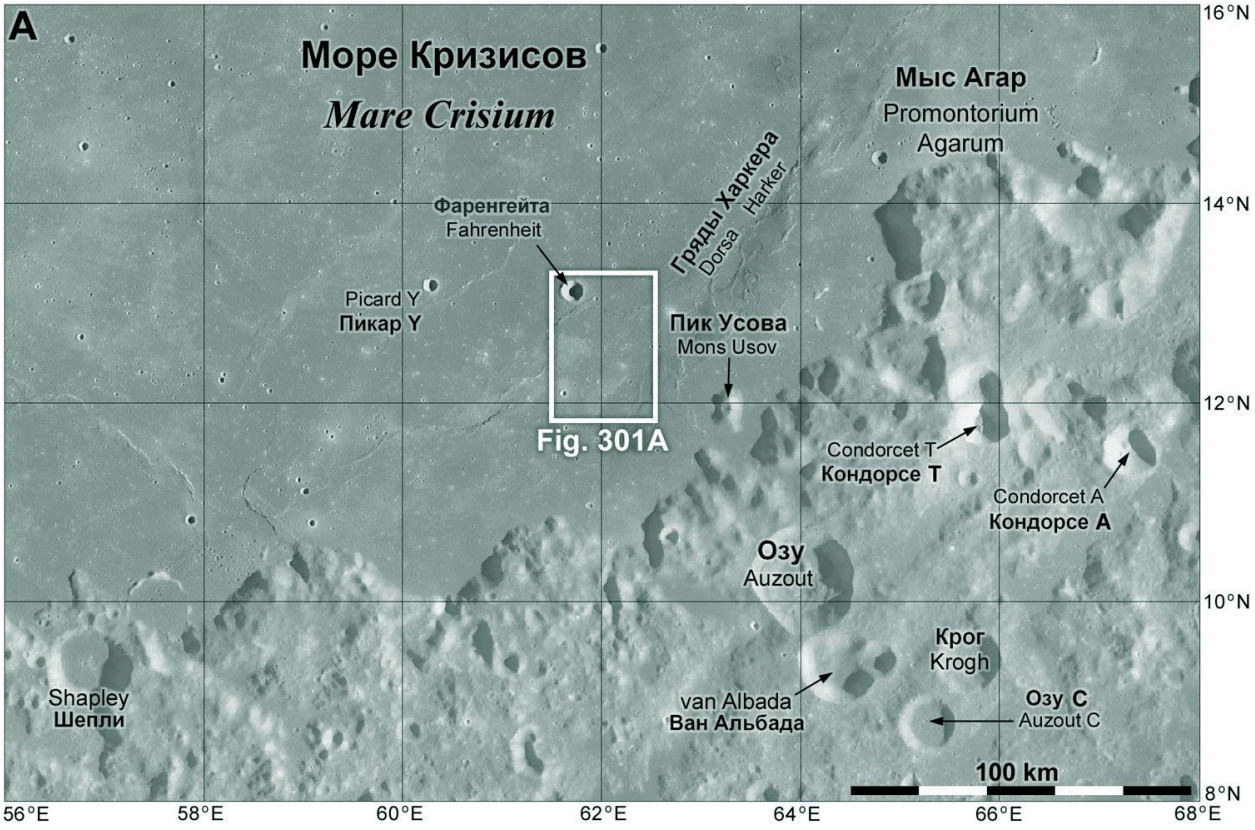
Time for a quick look at Luna 23, a failed sample return mission. Here are some details:

https://lroc.im-ldi.com/images/461

This starts with Luna 24 and looks at the earlier lander lower down the page. An annotated image shows what seems to have happened. The lander came in with some sideways velocity and toppled over... rather like some recent landings. It was able to communicate and even to operate its drill but couldn't collect a sample (also like IM-2).

May 6, 2025 - #moon #luna23

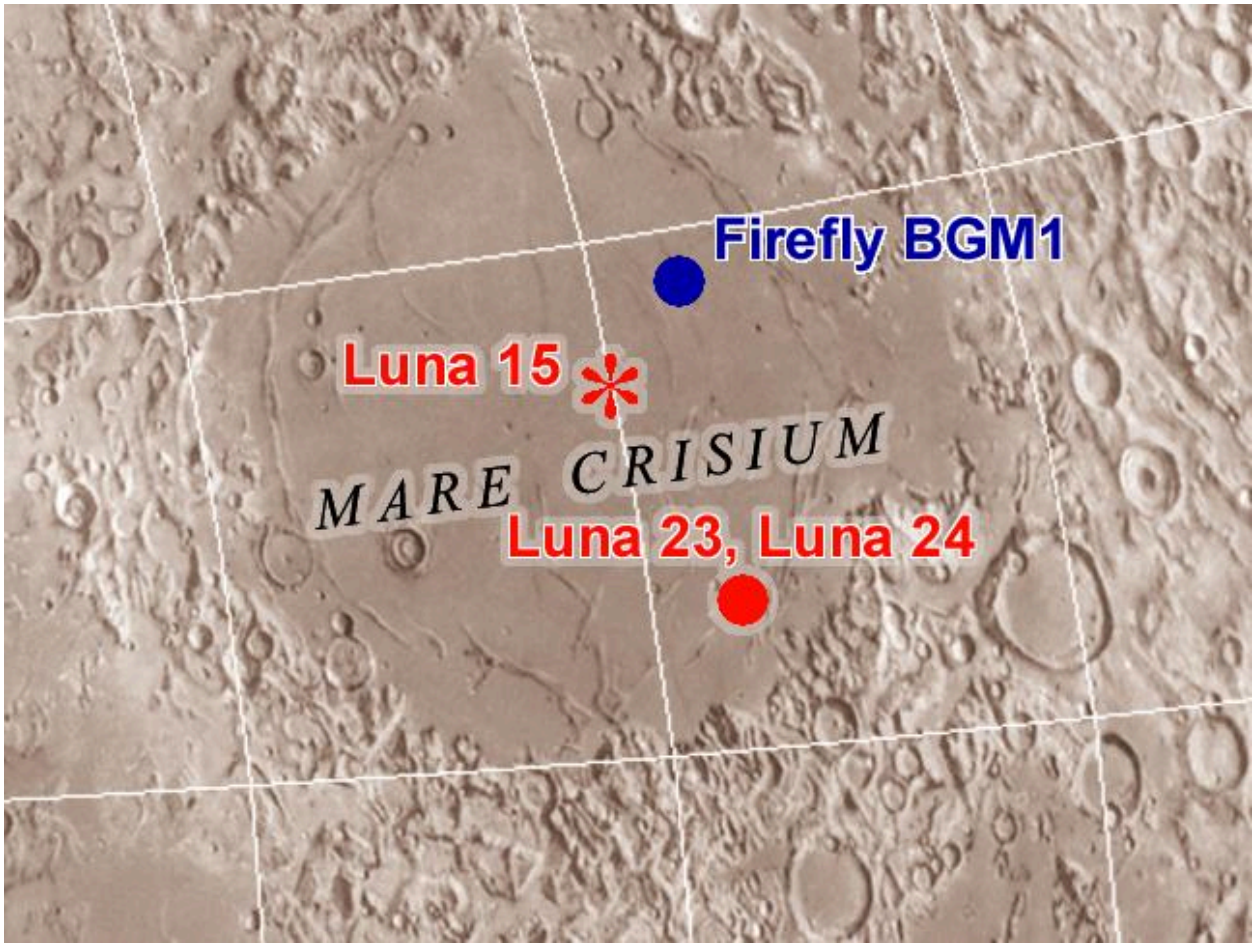
Here is a context map of the landing area in Mare Crisium. it is about 200 km south of the recent, very successful, Firefly Blue Ghost 1 landing site. Highlands about 50 km south of the site might have been visible but there was no camera on the lander.



A map of southern Mare Crisium showing the area in which Luna 23 landed. The landing site is inside a white rectangle at the centre of the map.

May 6, 2025 - #moon #luna23 #fireflyBGM1

This detail from my lunar sites map shows the Firefly site as well as the nearby Luna missions. As noted earlier, the Luna 15 site is very uncertain with several suggested locations. After the Hakuto M2 landing attempt I will release a new version of the whole map.



A small detail from my global map of lunar landing and impact sites. It shows the Luna 23 and 24 sites (the same point, at this scale) and the recent Firefly Blue Ghost Mission 1 site 200 km further north, as well as he very uncertain Luna 15 location.

May 7, 2025 - #moon #luna23

These maps zoom in on the landing site of Luna 23. I think I am repeating myself here, as we did cover this in the lunar landing site sequence. Speaking of.. I guess that will need updating later this year. I am hoping Hakuto M2 'Resilience' will land safely in 4 weeks and there could be 2 more attempts later this year.

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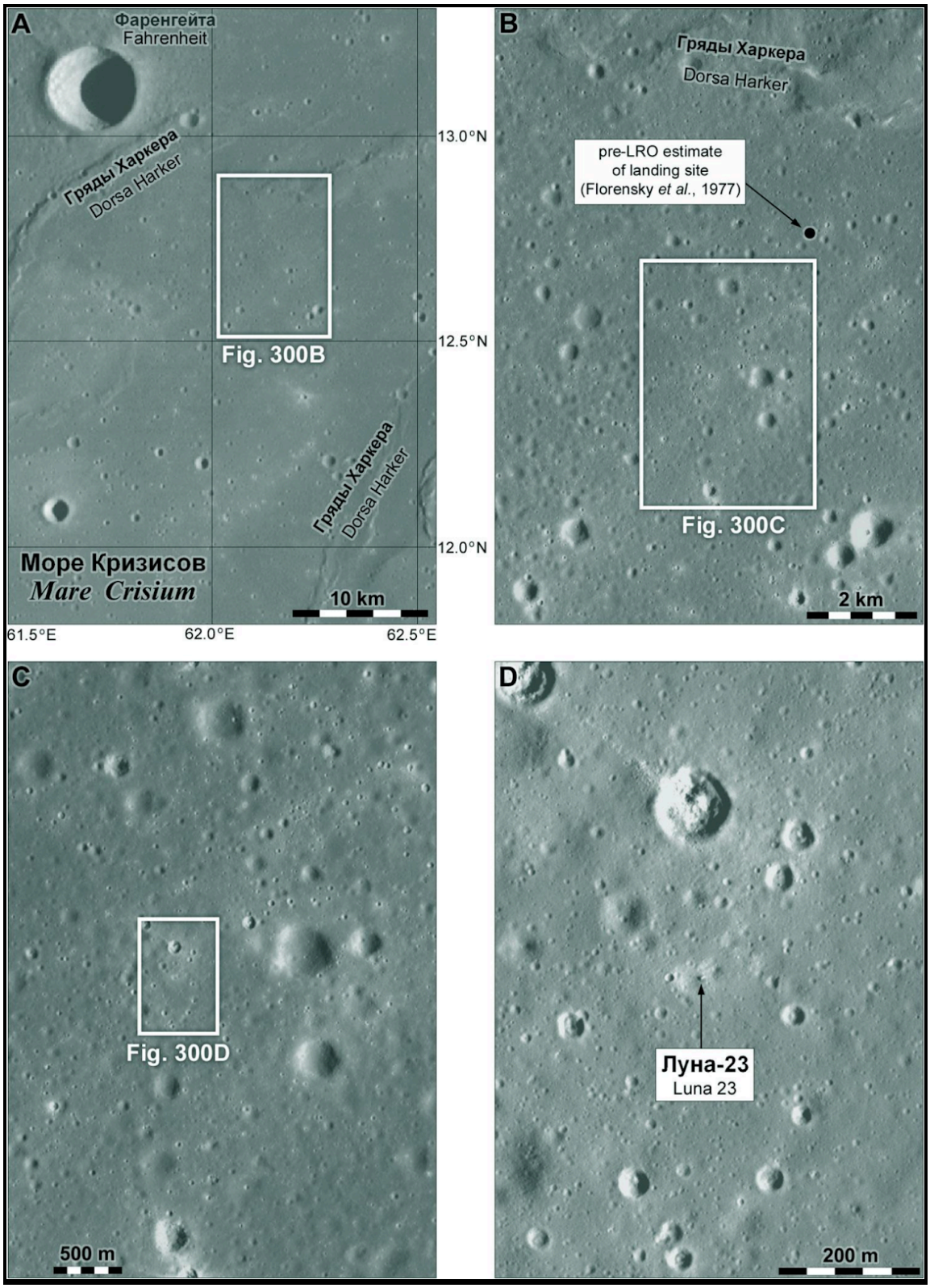
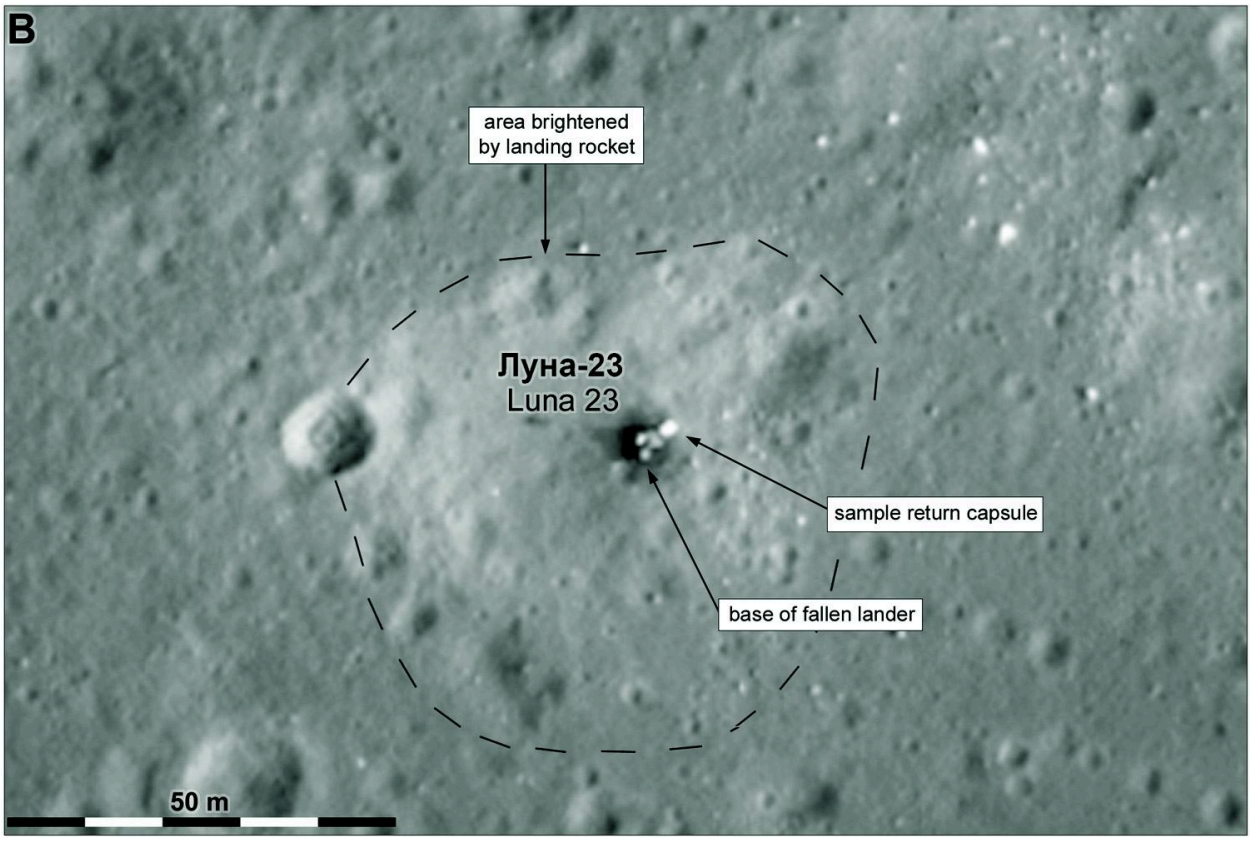


A sequence of 4 map panels zooming in on the Luna 23 landing site.

May 7, 2025 - #moon #luna23

Here is a close-up of Luna 23. It toppled and lies on its side with the return capsule at the upper right end. When LRO images first showed this the white object was interpreted as possibly a rock which the lander grazed while landing, damaging the drill. I think the fallen lander interpretation is probably correct. The area brightened by the landing rocket is hard to see on the south side and I may have taken it too far out.



A close-up view of the Luna 23 lander enlarged from the original LRO NAC image. It seems to have landed but fallen over towards the northeast, with its landing legs at the lower left and the return capsule at upper right. A patch around it is brightened by the landing rocket exhaust plume.

May 8, 2025 - #moon #luna24

Only 2 km northeast of Luna 23 is Luna 24, the last of the Soviet-era missions (but I will end this with Luna 25 and a look ahead). It was a successful sample return mission. The samples didn't quite seem to match the remote sensing data for the area and the LRO image suggests why - Luna 24 landed on the rim of a fresh crater called Lev, whose ejecta is not space-weathered (by micrometeorites and solar wind) like the average surface. There is still some uncertainty…

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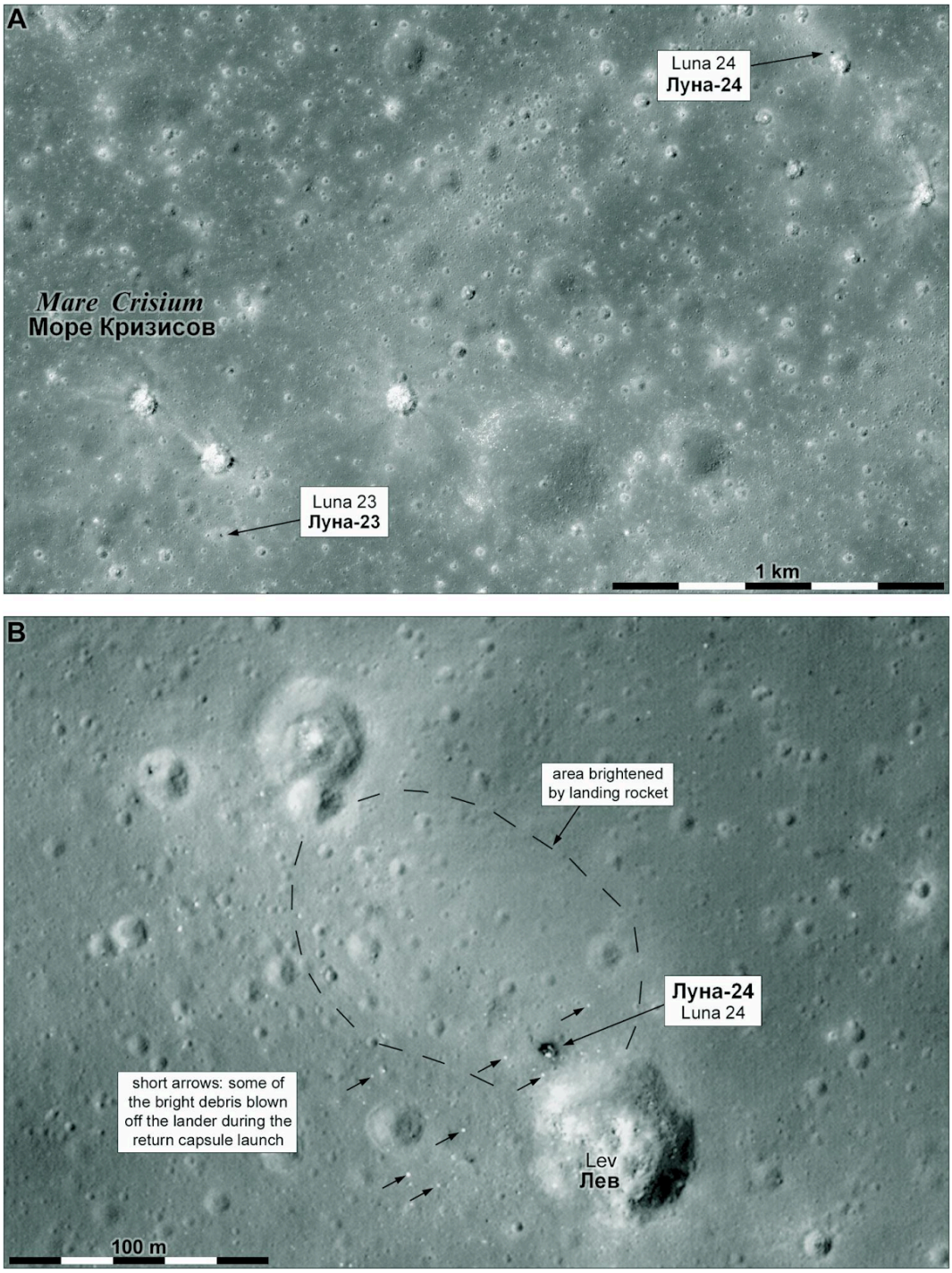

Two maps on LRO image bases of the Luna 24 landing site in Mare Crisium. The top one shows the context with Luna 23 and Luna 24 only 2 km apart. The bottom map is a close-up showing the lander on the rim of a small crater, a patch brightened by rocket exhaust and some bright spots which are probably bits of thermal blanket etc. blown off the descent stage.

May 8, 2025 - #moon #luna23 #luna24

Some Russians have argued that 23 and 24 are transposed in the interpretation I have given:

Kaydash, V. et al., 2013. Landing of the probes Luna 23 and Luna 24 remains an enigma. Planetary and Space Science, 89, pp.172-182.

Velichko, S. et al., 2022. Photometric analysis of the Luna spacecraft landing sites. Planetary and Space Science, 216, p.105475.

I don't find the argument convincing but it should be acknowledged.

May 9, 2025 - #maps #moon #luna24

Wrapping up Luna 24 with a zoom in to the landing site. This was a different design than the Luna 16/20 landers and it had no camera. The drill was fixed to the side of the lander to improve its ability to push down into the ground, so there was no need to view the sampling area to look for hazards. As an imaging person I can only say - tragic! I want pictures...

Tomorrow: Luna 25, and then I will look at Russian plans for future missions.

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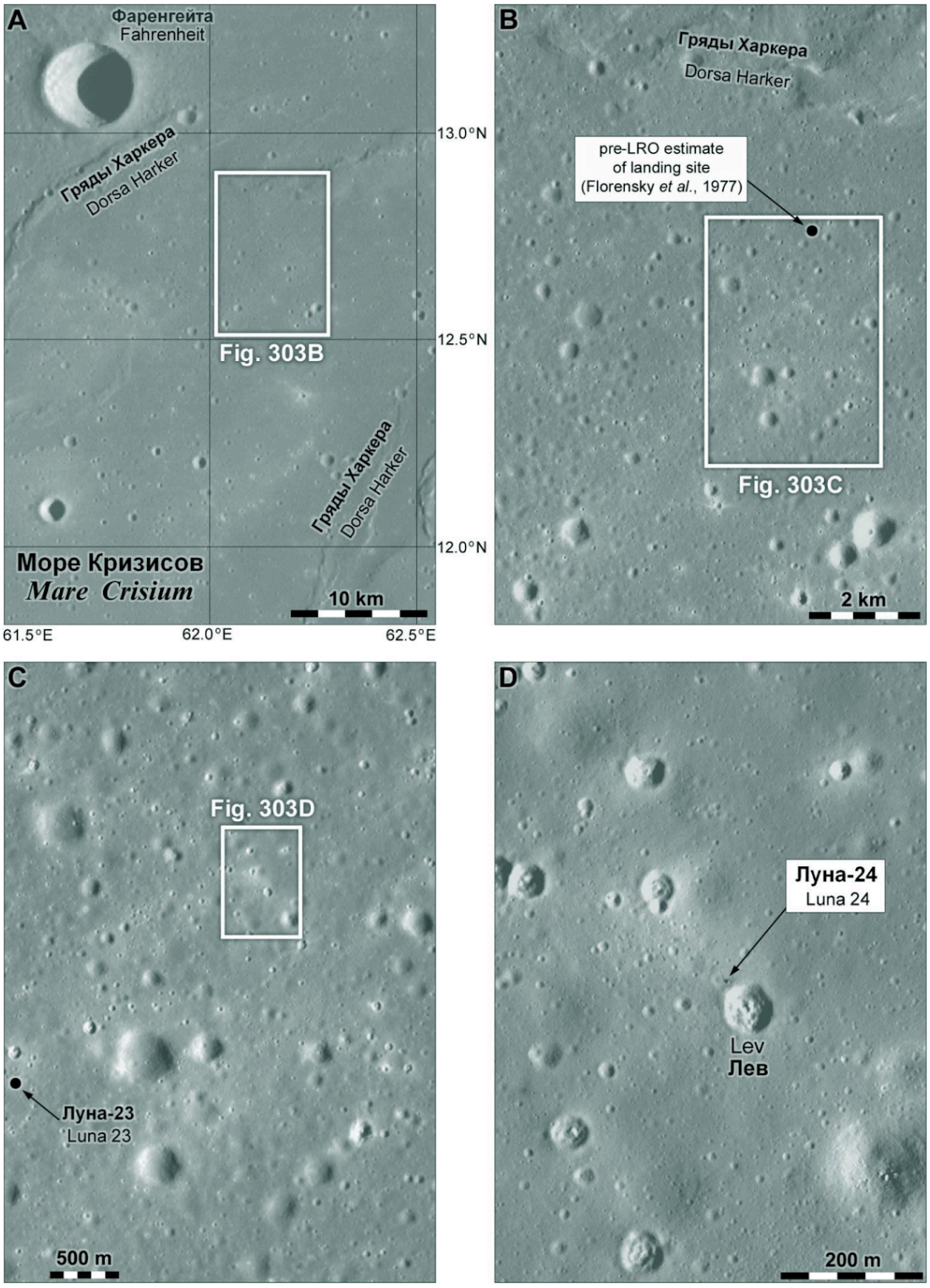

Four maps zooming in on the Luna 24 landing site. The second map also shows the pre-LRO estimate of the landing site.

May 10, 2025

We don't know much about landing site selection for Soviet-era landers, and what little I know I have mentioned already. That changes with modern landers, where many studies have been reported. Luna 25 is an interesting case. The mission went through several iterations and names, beginning with Luna-Glob. Glob = 'globe' and this was supposed to be a global geophysical network mission:

Galimov, E.M., 2005. Journal of earth system science, v. 114, pp.801-806.

May 10, 2025 - #moon #luna25

The next mission was going to be Luna-Resurs (= resource), which would study potential lunar resources such as polar volatiles. Later Luna-Resurs was taken as the name of a sequence of landers and Luna-Glob was the first of them. Later still the sequence took the names Luna 25, 26, 27 and so on to show continuity with past missions. India joined for a while with an Indian rover on a Russian lander so the name Chandrayaan was used too.

May 10, 2025 - #maps #moon #Lunaglob

These are the first set of sites for Luna-Glob. Two circles of small penetrators and two large penetrators carry geophysics instruments (proximity to Apollo sites is to match new data to old more easily). A polar lander goes to a shaded site in Shoemaker crater near the pole. The polar resources became the most important part of this later.

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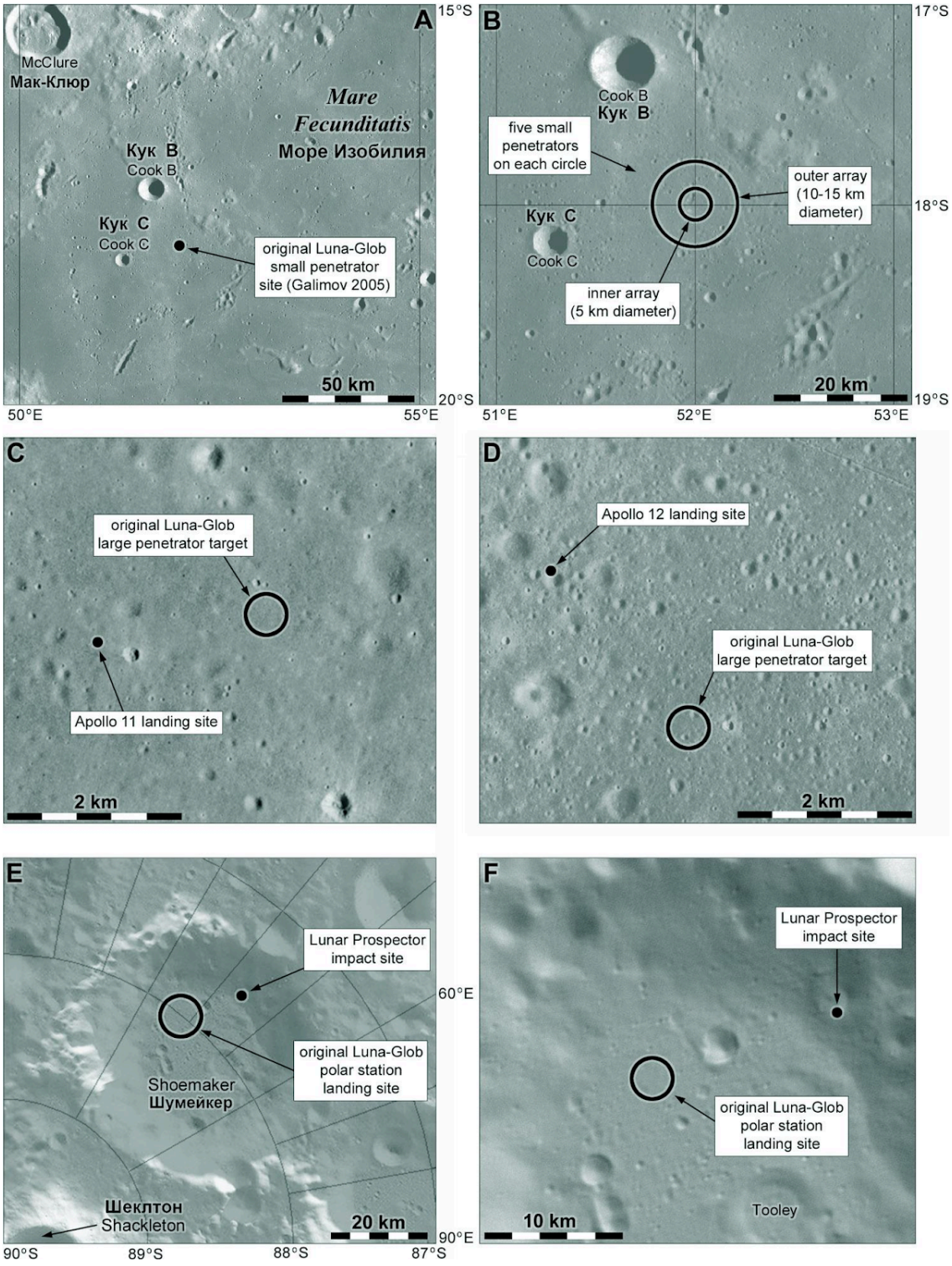
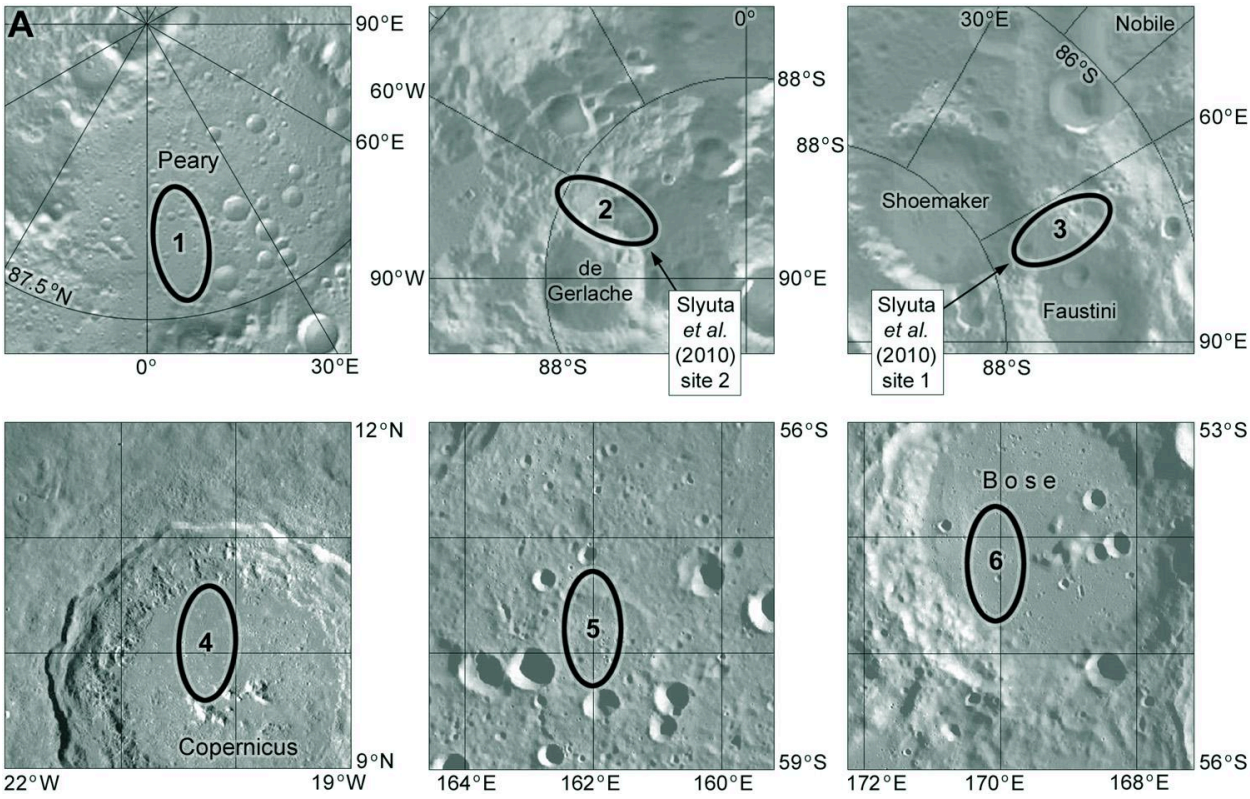


A first set of sites for Luna-Glob, a precursor mission study for Luna 25. Penetrators establish a small local network in Mare Fecunditatis and two larger stations near Apollo 11 and Apollo 12. A lander goes to a polar site in Shoemaker crater.

May 11, 2025

By 2009 the next lunar mission was called Luna-Resurs (resource) and site selection was moving towards the poles. Landing sites were described by Evgeny Slyuta and colleagues in 2009 and 2010. The 2009 set of 6 sites had 1 near the north pole, 2 near the south pole and 3 at low to mid-latitudes if polar sites were too challenging (Copernicus, and 2 in the South Pole-Aitken basin). The 2 south polar sites were preferred in 2010.



Six sites suggested for Luna-Resurs in 2009. One is near the north pole, two are near the south pole, in illuminated areas rather than shadows. Three more were in low to mid-latitudes in case polar sites were too difficult. One of those was in Copernicus and two were in the South Pole-Aitken basin on the far side of the Moon. The 2 south polar sites were the preferred locations in a 2010 presentation.

May 11, 2025 - #maps #moon #lunaglob

Then in 2011 two international workshops were held in Moscow - with presentations still online today:

http://www.iki.rssi.ru/conf/2011-lg/

(open page in something that will translate it for you if necessary, but many of the presentation PDFs are in English).

They included proposals for sites at north and south poles. These maps show both sets as well as some later additions. All the modern datasets and GIS analytical tools are used, a big change from the old days!

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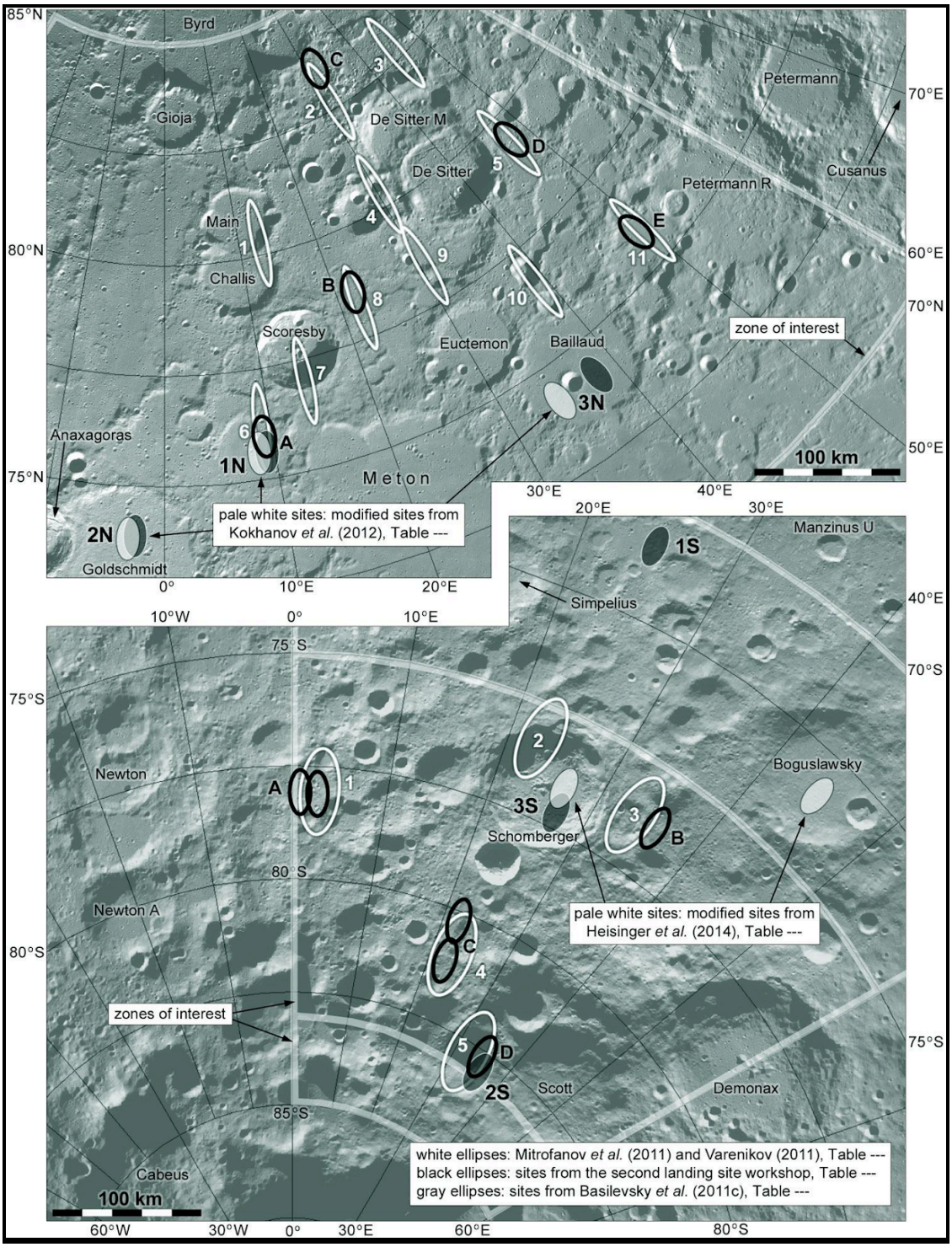

Maps of the north and south polar nearside areas where landing sites for Luna-Glob and/or Luna-Resurs were being suggested in 2011.

May 11, 2025 - #moon #lunaglob

One very important data source for this site selection work was the Russian LEND neutron detector flown on Lunar Reconnaissance Orbiter. Its results can be interpreted to reveal hydrogen in the surface materials. Most or all of these landing sites are in areas of higher hydrogen content. Some are too rough or steep and would be dropped later.

May 12, 2025 - #maps #moon #lunaglob

In 2015 our mission was still being called Luna-Glob, and site work had converged on one place, the 90 km wide crater Boguslawsky at 73 south. This map shows two ellipses described by Ivanov et al. in Planetary and Space Science. They are in view of Earth all the time and are in the smoothest parts of the floor. Craters with flat floors like this should have central peaks, so in this case any peak is buried under the material of the crater floor.

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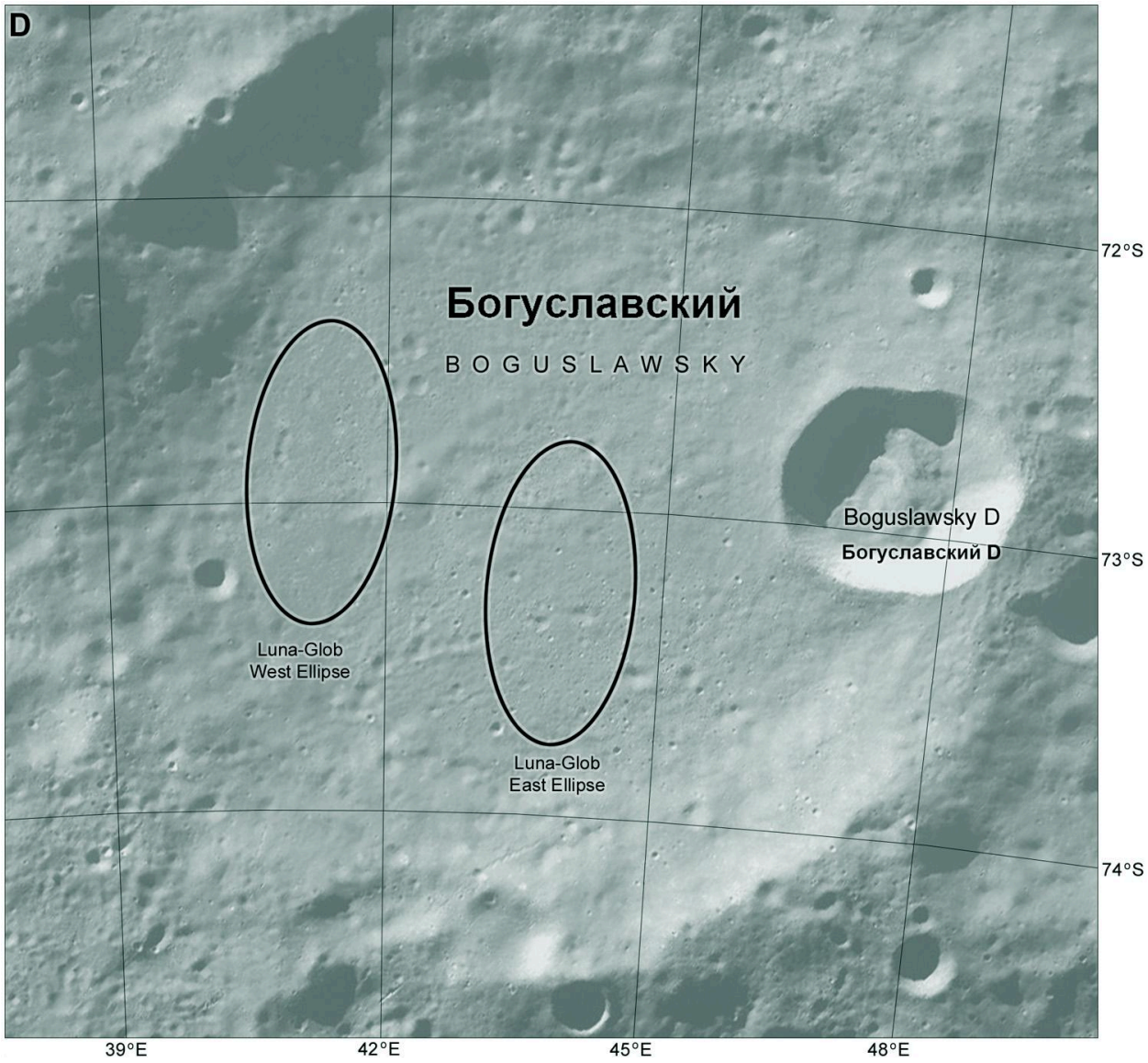


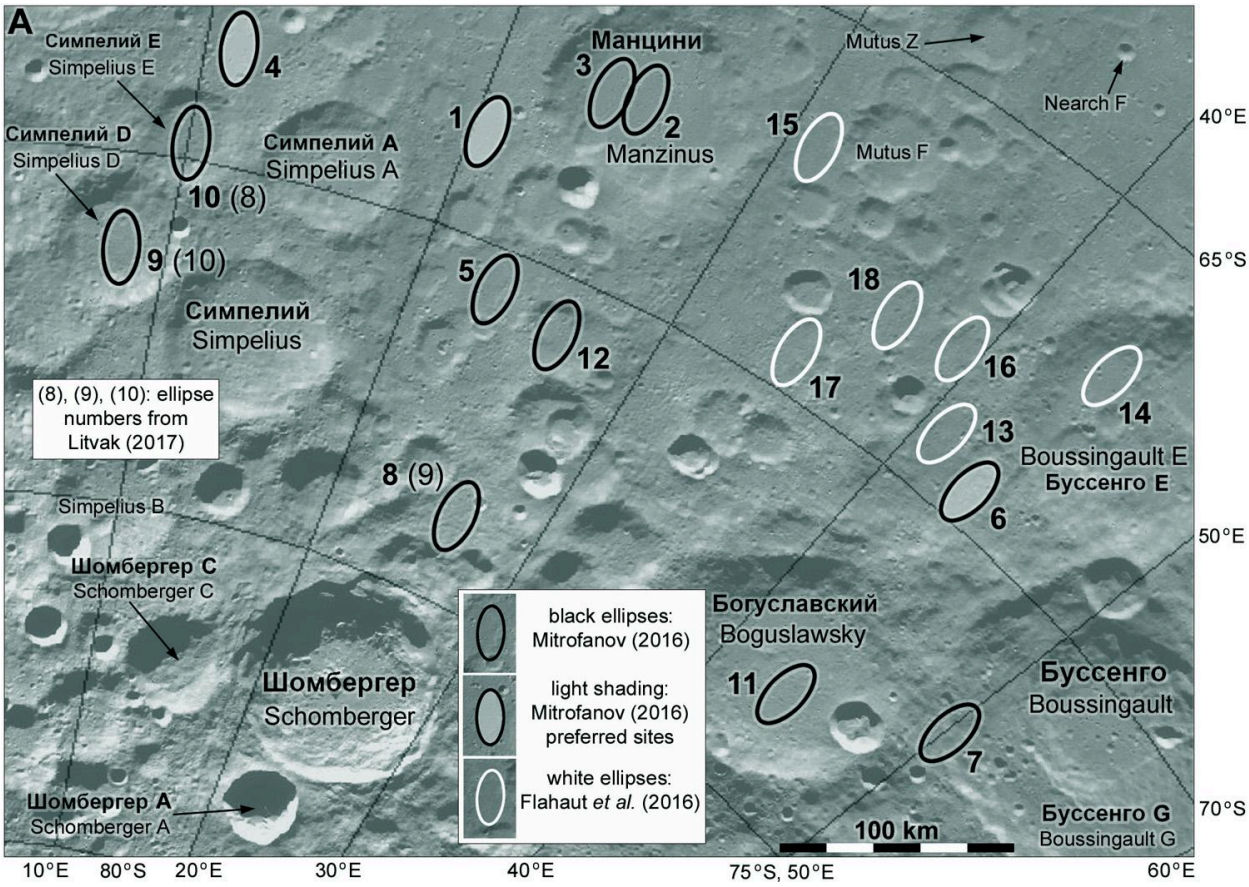
Two Luna-glob ellipses in crater Boguslawsky described by Ivanov et al. in 2015. Each is smooth enough to land in and the surface is made of debris thrown into the crater from other impacts (deep enough to bury the expected central peaks). That means we don't really know where the debris came from. But the East Ellipse is closer to a 20 km crater on the eastern wall of Boguslawsky and would sample its ejecta. We do know where that came from - the actual wall and rim of Boguslawsky itself. So that ellipse was preferred.

May 12, 2025 - #moon #lunaglob

Here's a bit of a problem. The crater floor is thought to be made of debris thrown in from other impacts, so we don't really know where it came from. But the East Ellipse would sample ejecta from a smaller crater (Bog. D) which has excavated the wall and rim of Boguslawsky itself. So we do know where that came from and that ellipse was preferred.

May 13, 2025 - #moon #lunaglob

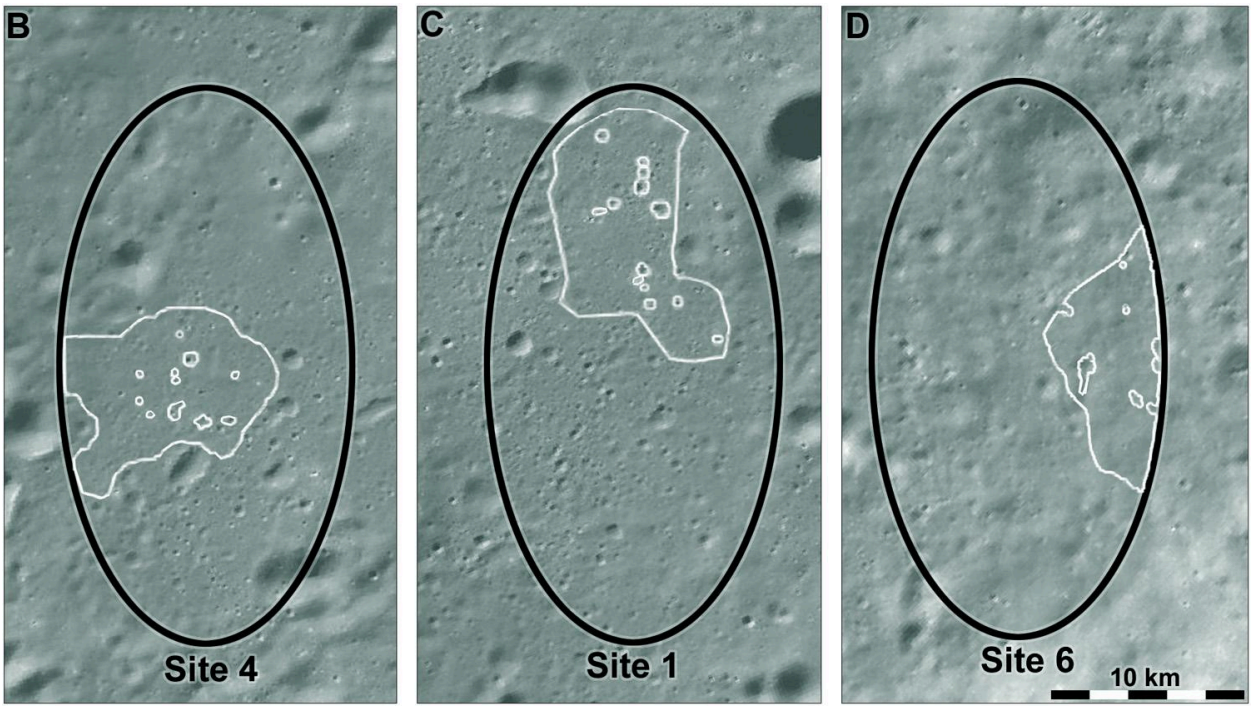
That landing site in Boguslawsky was not the end of the story. This map shows 2016 site study results by Russians and by a group led by Jessica Flahout. It might seem similar to the last few posts but check the latitudes. The 2010 sites were around 88 south. The 2011 sites were at 75-85 south. The Boguslawsky sites are at 73 south. These are 65-75 south and the preferred ellipses are about 68-69 south. The poles are tricky.



A set of sites for Luna-Glob from 2 studies in 2016. Over the last few posts the sits have been moving away from the pole and the preferred sites here are about 68 or 69 degrees south.

May 13, 2025 - #maps #moon #luna25

I'm showing these maps to illustrate the number of sites suggested over the last 15 years for Luna 25 and its precursors. By about 2018 the mission name was settling on Luna 25. The 3 sites shown as preferred are the final sites, shown in this map in more detail. Site 6, north of Boguslawsky, was the primary landing site for Luna 25. White outlines show safest areas in the ellipses from a 2021 study. Now we can move on to the actual mission.



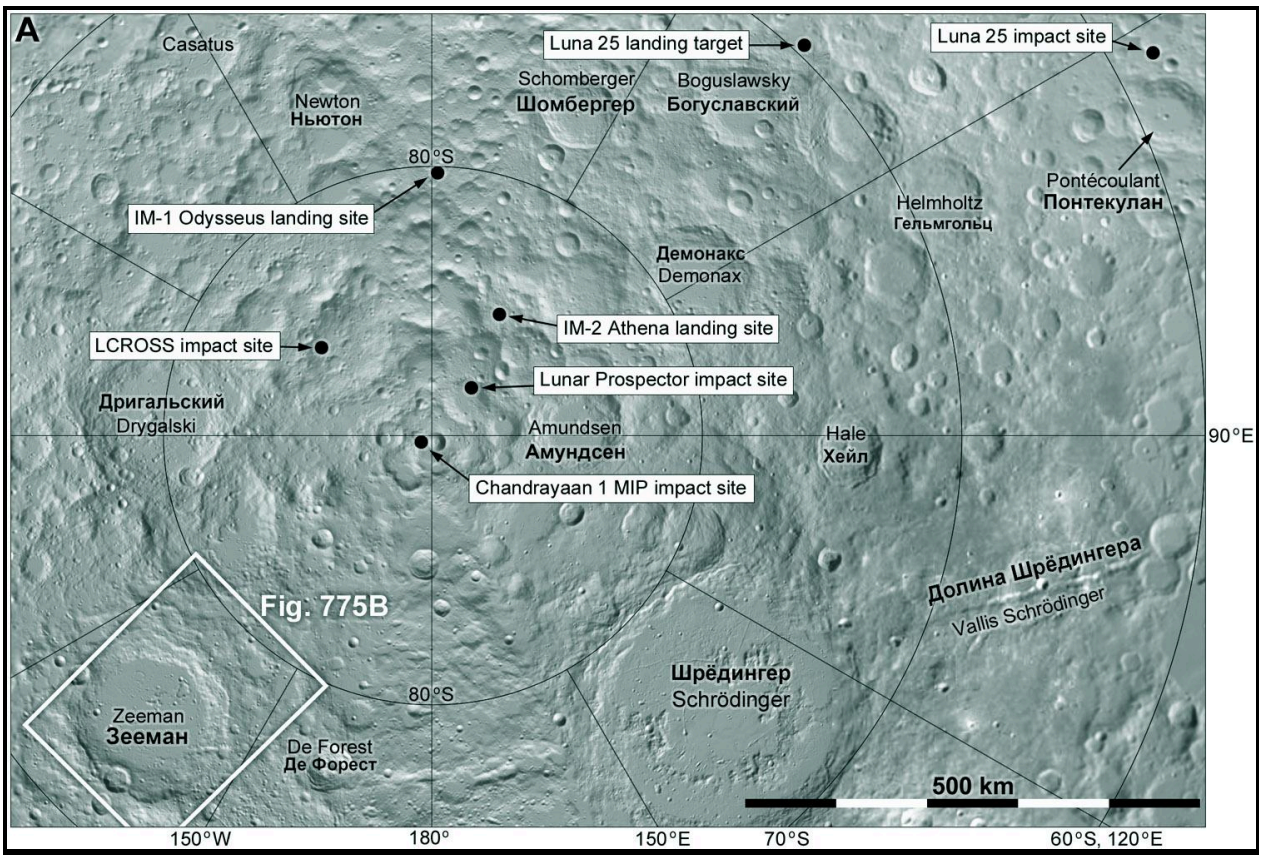
Three maps showing details of the three ellipses (each 30 by 15 km) chosen for Luna 25. The smoothest areas in each ellipse are outlined in white from presentation by Krasilnikov et al. in a 2021 symposium in Moscow.

May 14, 2025 - #maps #moon #luna25

At last we get to Luna 25 itself. It would have been an interesting mission. Here is the NSSDCA page for it:

https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=2023-118A

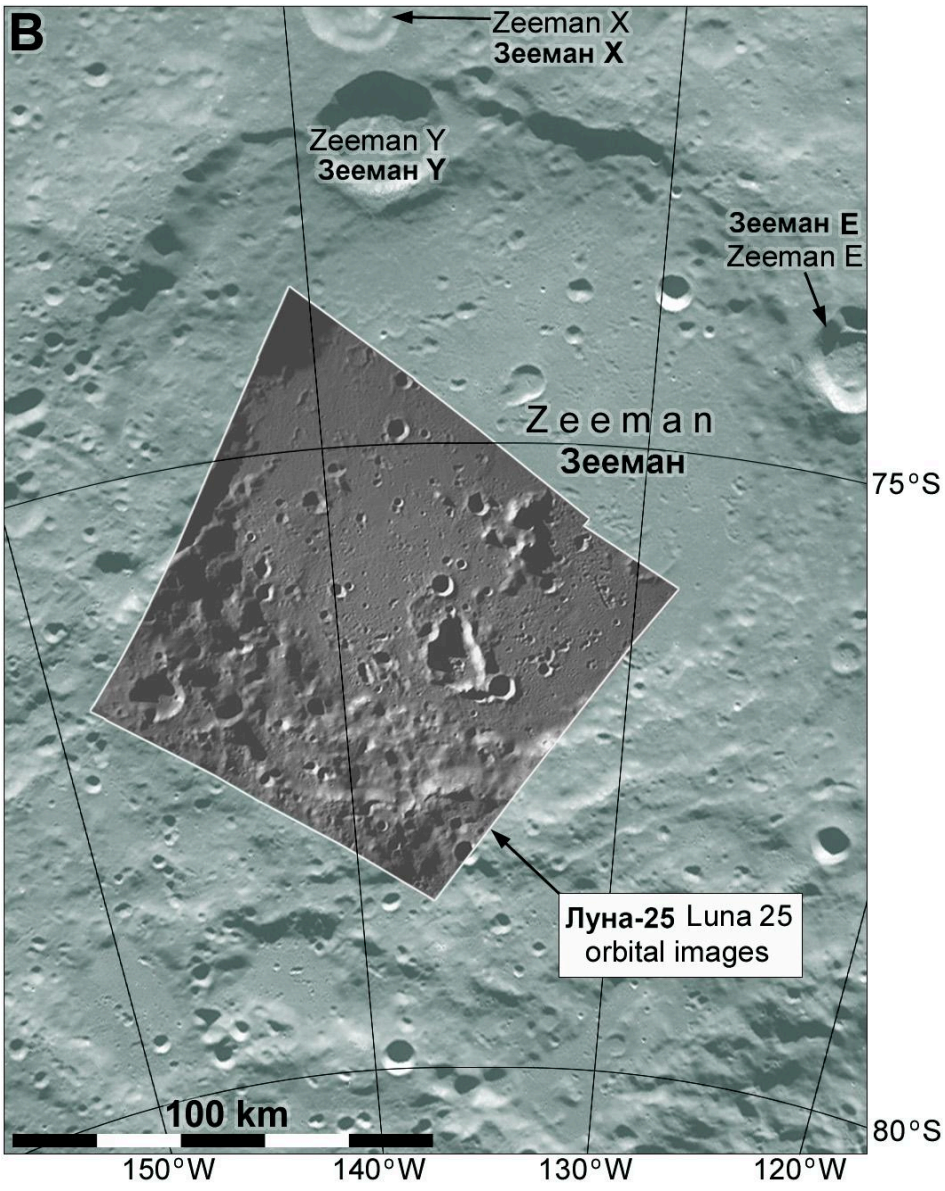
A robotic arm would collect a sample from a small workspace close to the lander and deliver it to the lander for analysis. This would be repeated once a month for a year. But it was not to be. Flight control issues caused a braking overburn which caused a crash northeast of the target site. This map puts it into context.



A context map for the Luna 25 mission. Other landing and impact sites are plotted around the south pole. An area imaged from orbit by Luna 25 is shown at lower left and the impact site and landing target are at upper right.

May 14, 2025 - #maps #moon #luna25

This map shows the crater Zeeman, location of the only images known to have been taken from orbit. Surface composition was measured by one instrument but I have not located the observation site yet. A dust detector collected data in orbit 2 days before the crash. So there was some small science return from the mission.



Luna 25 images showed this area in Zeeman crater near the south pole. Some geological analysis was done, hinting at the presence of water in surface materials.

May 15, 2025 - #maps #moon #luna25

Here we zoom in on the Luna 25 impact site. The location was shown in the context map yesterday. How do we know this is the impact site? Here is the LRO camera page on it:

https://lroc.im-ldi.com/images/1311

The location was predicted by mathematicians at the Keldysh Institute, and 2 km away is a small crater with a south-facing spray of ejecta which was not there 2 years earlier. It's what we expect, close to where we expect, so very likely to be the impact.

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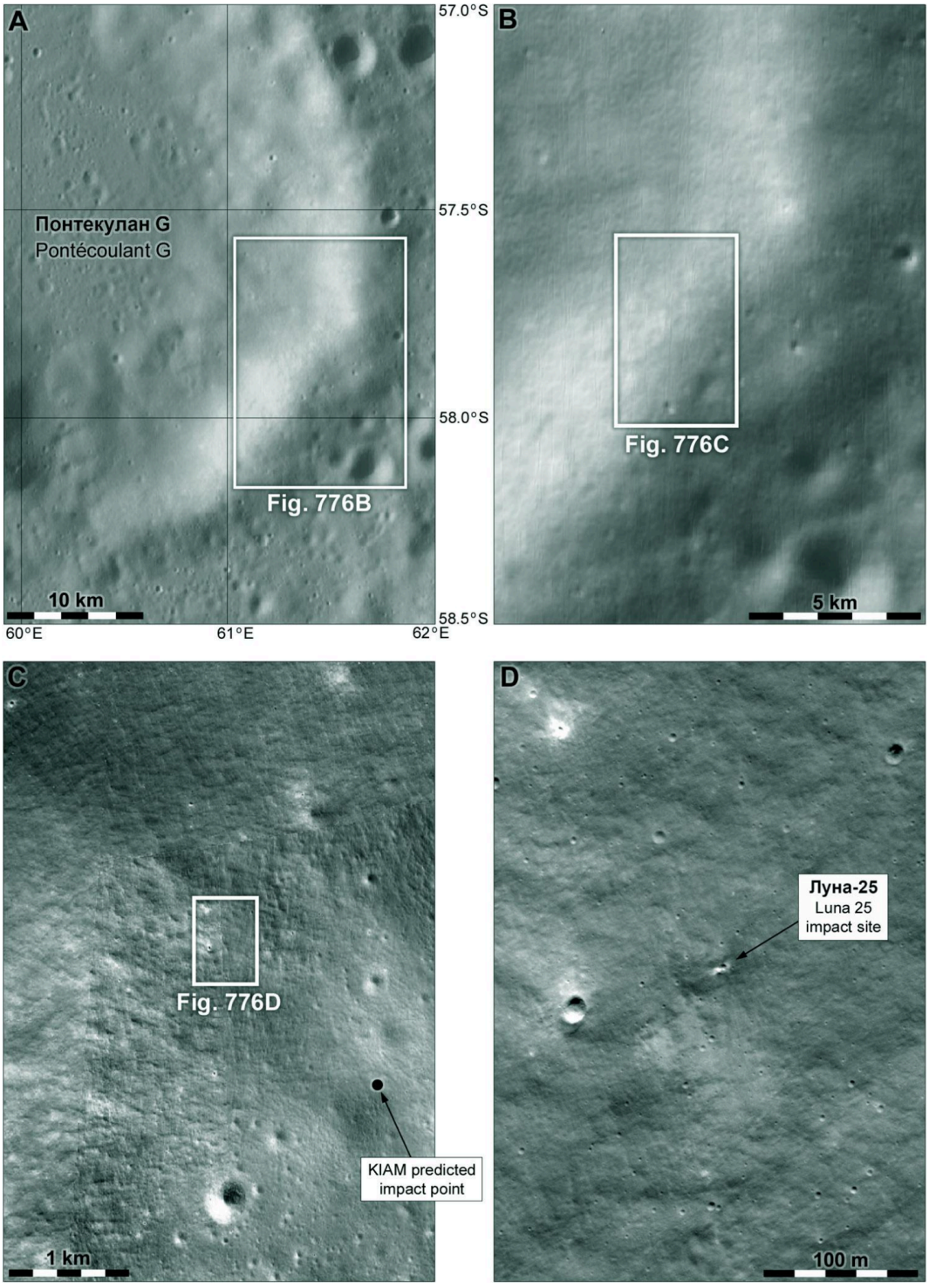

Four maps zooming in on the south rim of a crater called Pontecoulant G, where a small crater with a spray of ejecta extending south is found 2 km from the predicted impact point of Luna 25. The crater was not present in an image taken 2 years earlier.

May 15, 2025 - #maps #moon #luna25

Here's a closeup of the Luna 25 impact site. All these impacts from orbit show a faint downrange ejecta fan, not the roughly symmetrical bright ejecta expected for a natural hypervelocity impact. One very important factor here is LRO which has imaged basically the entire surface of the Moon multiple times, so there is pretty much always going to be a pre-impact image, often with similar lighting.

Tomorrow - a quick look ahead to Russia's future lunar plans.

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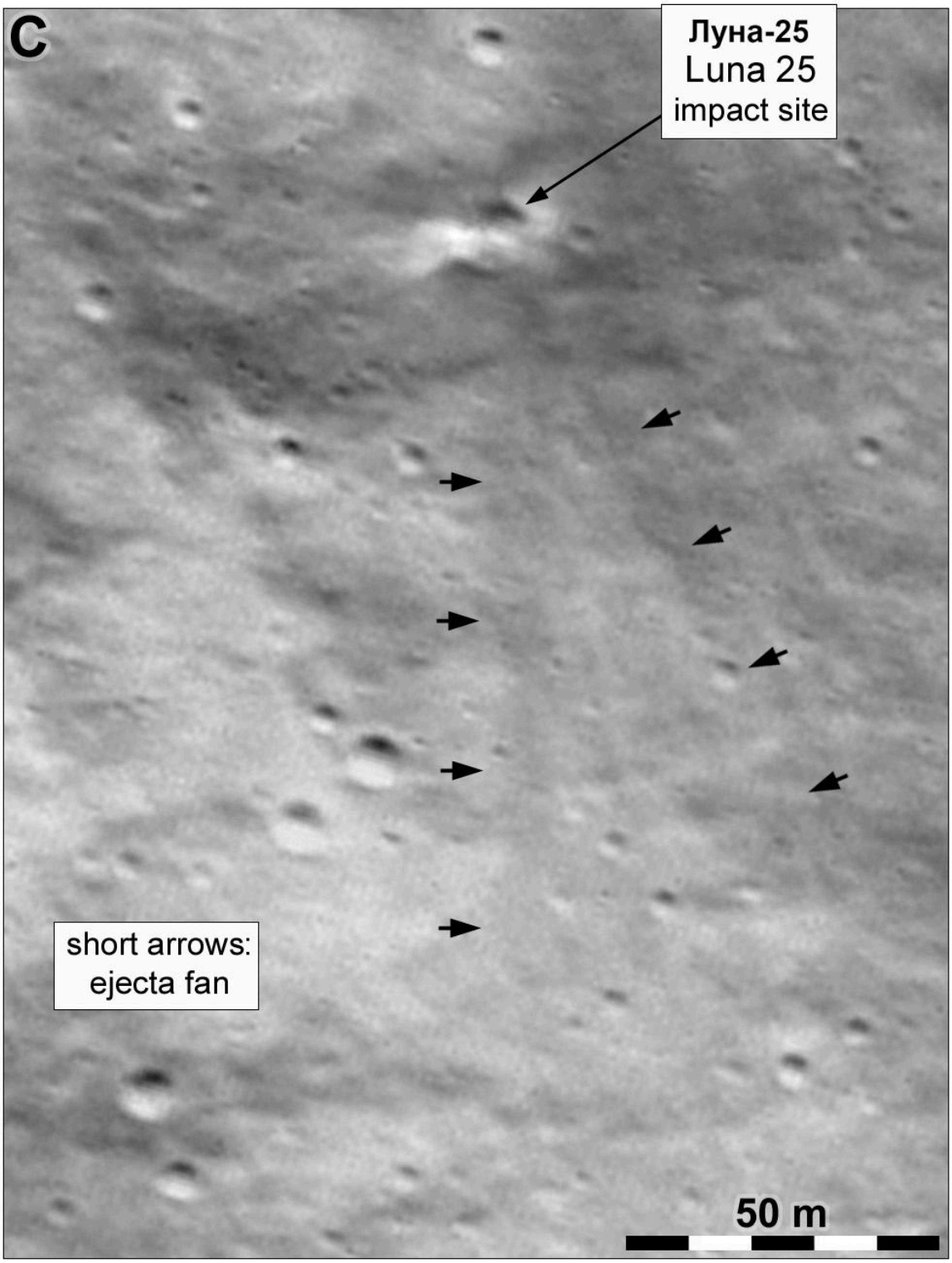

The impact crater and ejecta formed by the Luna 25 spacecraft. The crater is about 10 m across and a faint ejecta fan extends southwards (downrange) from it.

May 16, 2025 - #maps #moon #luna27

We are up to date with our Russian lunar missions, but let's look ahead a bit. The next mission is likely to be Luna 26, an orbiter bristling with instruments:

https://www.russianspaceweb.com/luna_glob_orbiter.html

It might fly in 2027 but timing is very uncertain. After that there two landing missions (possibly 3 landers), Luna 27 and 28. The attached map shows a 2019 version of a set of Luna 27 landing sites by Maya Djachkova et al. It illustrates an important point…

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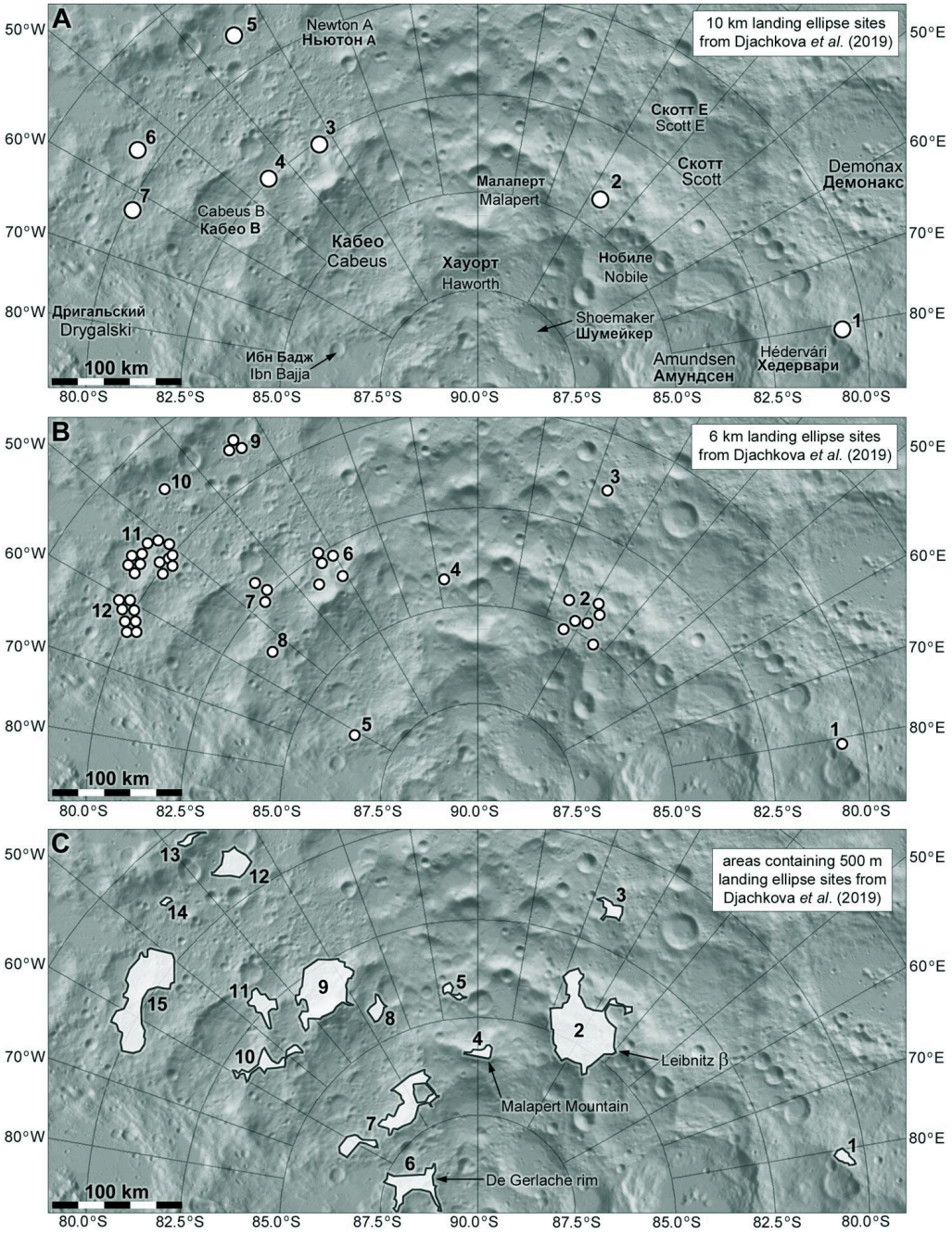


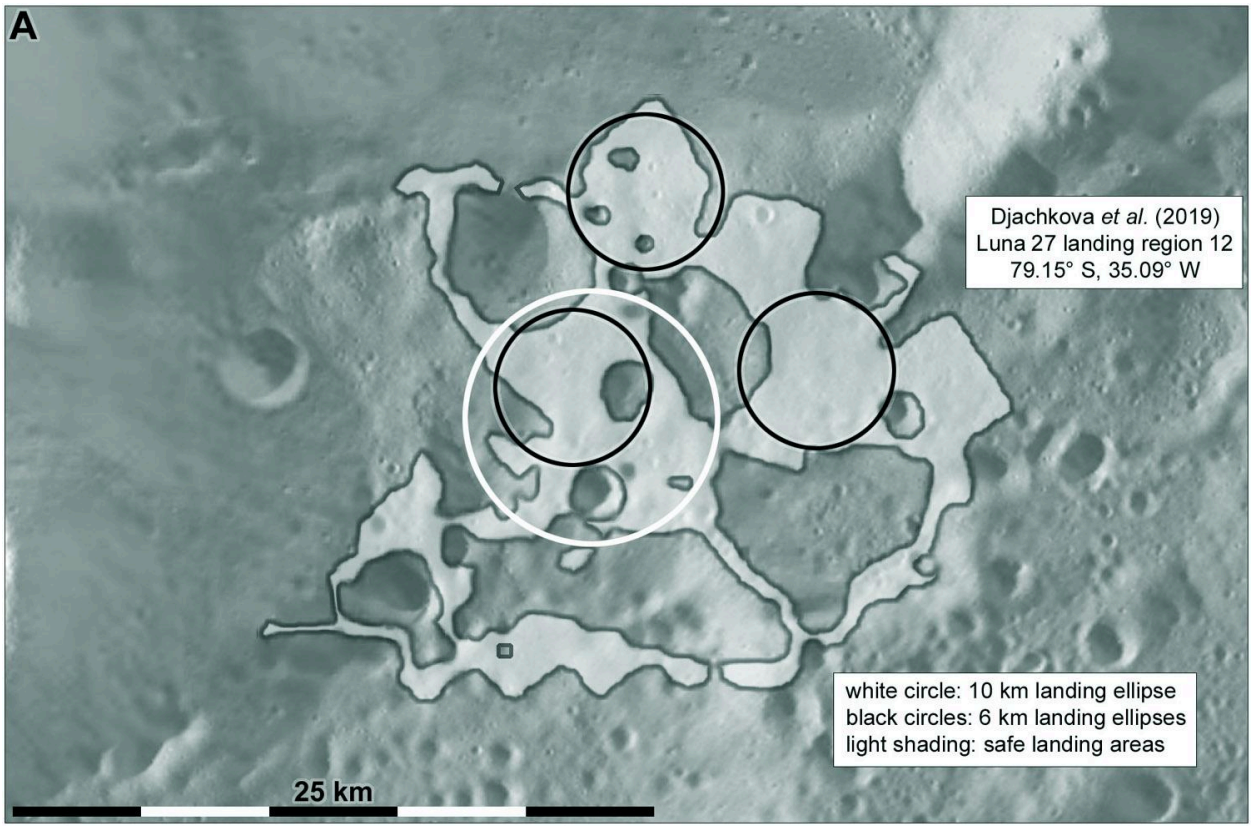
Three maps showing potential landing areas for Luna 27, a future Russian moon lander which might fly in about 2028. The top map shows just a few locations where 10 km diameter sites might be located. They fit topographic, illumination and hydrogen abundance data. The middle map shows a larger number of sites 6 km across - the smaller size can fit in more places, still in the general areas with elevated hydrogen. The bottom map shows areas where large numbers of 500 m sites can be placed. This study was presented at the 10th Moscow Solar System Symposium in October 2019 by Maya Djachkova and colleagues.

May 16, 2025 - #moon #luna27

... and that point is, smaller landing ellipses are easier to locate. The basic pattern is controlled by hydrogen abundance, and in H-rich areas the big (10 km) circles only fit in a few locations. Smaller circles (6 km) are easier to fit in low slope areas. Drop to 500 m diameter and hundreds of sites might work, so they are mapped as irregular areas containing many sites. Precision landing is a game-changer for future missions.

May 17, 2025 - #moon #maps #luna27

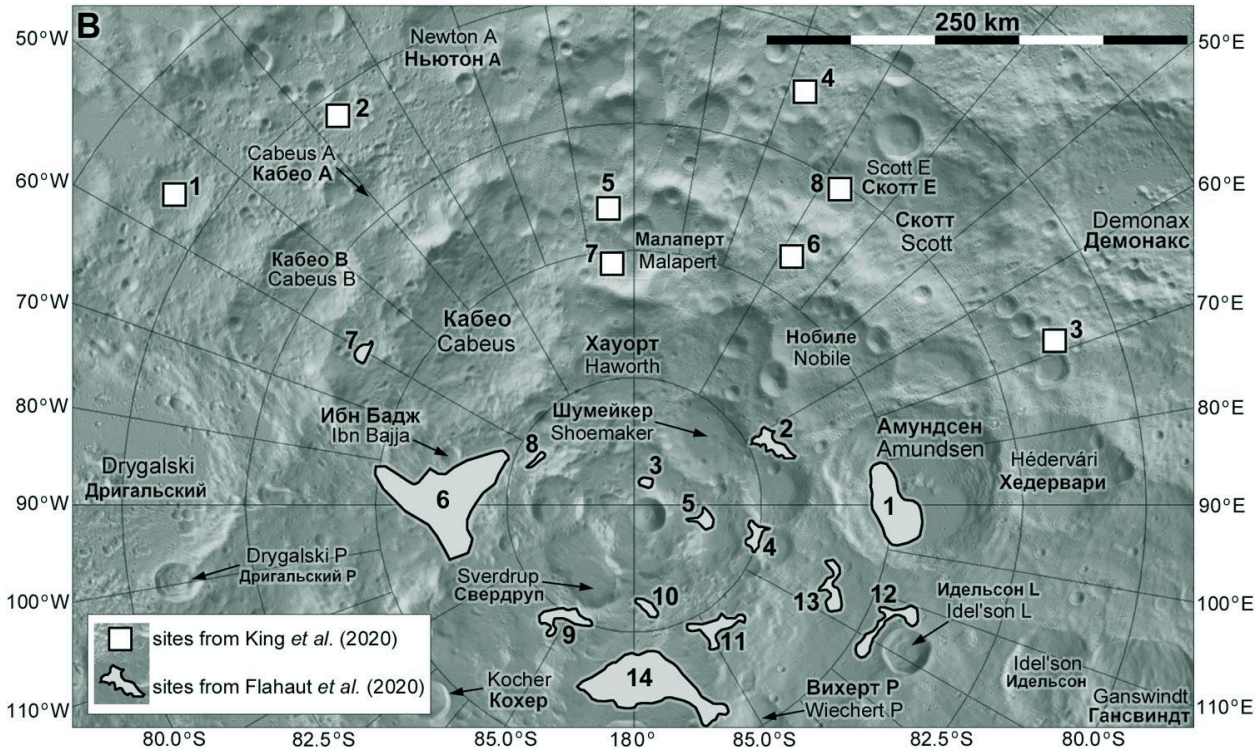
Here's an illustration of this point about smaller circles, using an example redrawn from Maya Djachkova's presentation on Luna 27 at a symposium in Moscow in 2020. The irregular light area is mostly safe to land in, a few small craters excepted. Lots of 500 m circles could be squeezed into it. But only 3 spots can take a 6 km circle (and they are not perfect), and only one 10 km circle is possible.



One of the sites suggested by Djachkova in 2019 (the previous post) is enlarged to show how landing ellipses (here, circles) can fit in it. A very irregularly shaped area is safe to land in (light patch with a dark outline). Lots of small circles, 500 m across, could be placed in it. But only 3 places can fit a 6 km circle and only 1 can fit a 10 km circle, and they are not perfect.

May 17, 2025 - #moon #maps #luna27

Other people also studied Luna 27 landing sites. This map shows two sets of sites from 2020 papers. King et al. studied Luna 27 sites on a list provided by ESA, which was to fly a payload called PROSPECT to look for volatiles. ESA cancelled that after the Ukraine war started, and it will now fly on a CLPS lander. Flahaut et al. looked at many sites and identified some suitable for Luna 27. They preferred site 6 near Ibn Bajja crater.



Map of the lunar south pole showing two sets of sites published in 2020. One set is from a list prepared by ESA, who were to fly instruments on Luna 27. They were withdrawn after the Ukraine war started and will fly on a CLPS mission instead. The other set is part of a bigger study of sites by Jessica Flahaut et al., and they identified some which were suitable for Luna 27.

May 18, 2025 - #moon #maps #luna27

I want to give a view into the complexity of site selection work for these missions. The datasets are amazing, the mapping tools magical to someone like me who trained with ink pens on mylar. And to follow the story you need to spread the net wide - journals, conferences and workshops, social media. It's a full-time job trying to record it all! Here is the next step for Luna 27, M. Djachkova's paper - updated from the 2019 symposium. Similar but not identical.

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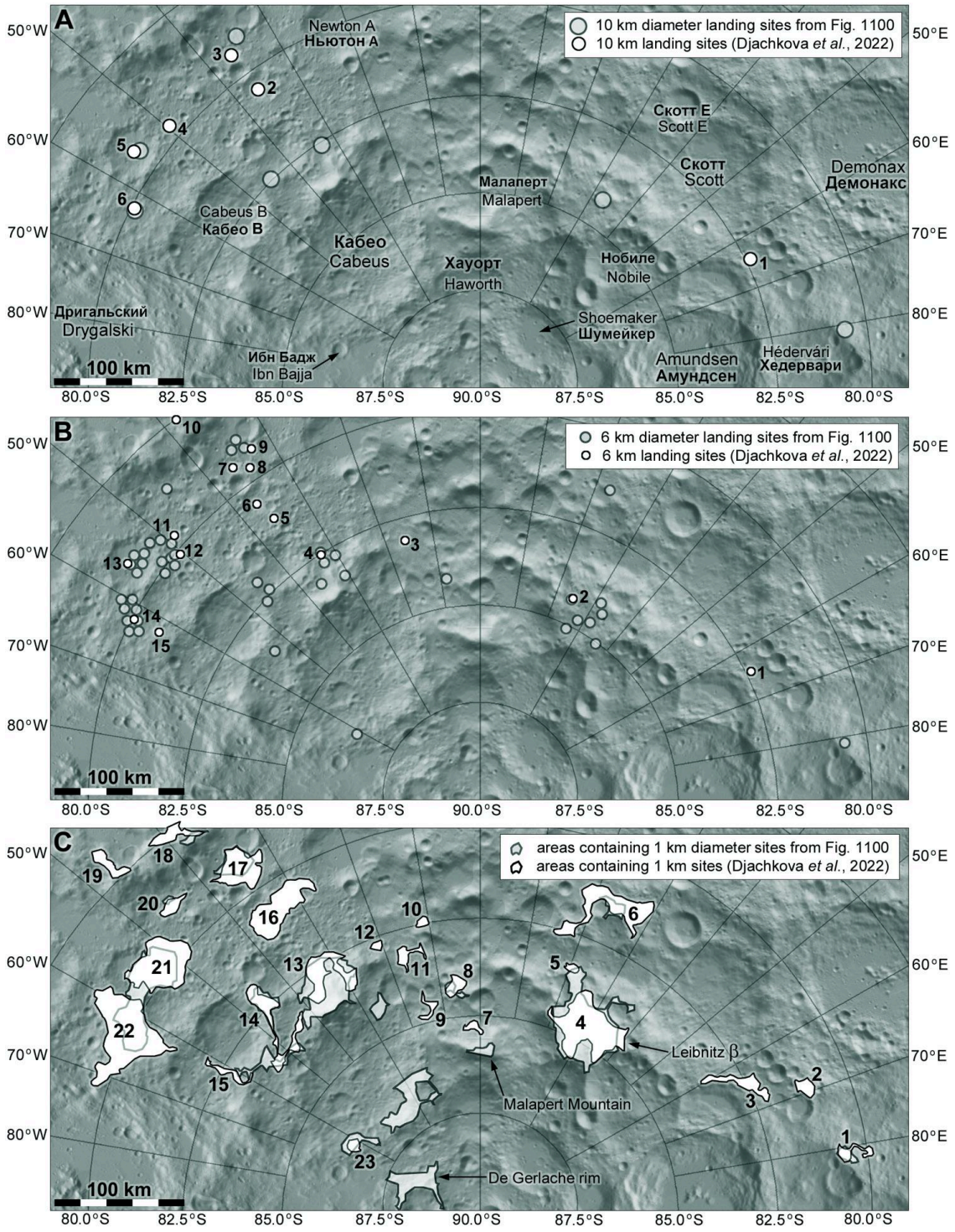

A 3 panel map essentially the same as one posted 2 days ago, showing work by Maya Djachkova on the Luna 27 landing site. But this is a 2022 journal publication and it is significantly updated from the 2019 symposium presentation. Sites 10 km, 6 km and 1 km across are mapped near the south pole.

May 18, 2025 - #moon #maps #luna27

Sharp-eyed readers will note a discrepancy - the bottom panel mentions 1 km diameter sites from Figure 1100 (that's a placeholder figure number from the 2019 iteration). But that map mentions 500 m circles - is it radius or diameter? Now I have to resolve this contradiction.

Meanwhile, here is a 2024 study with completely different results. 5 big ellipses, 10 small circles (this time 500 m radius). Who knows where the lander will actually go? Even more tomorrow…

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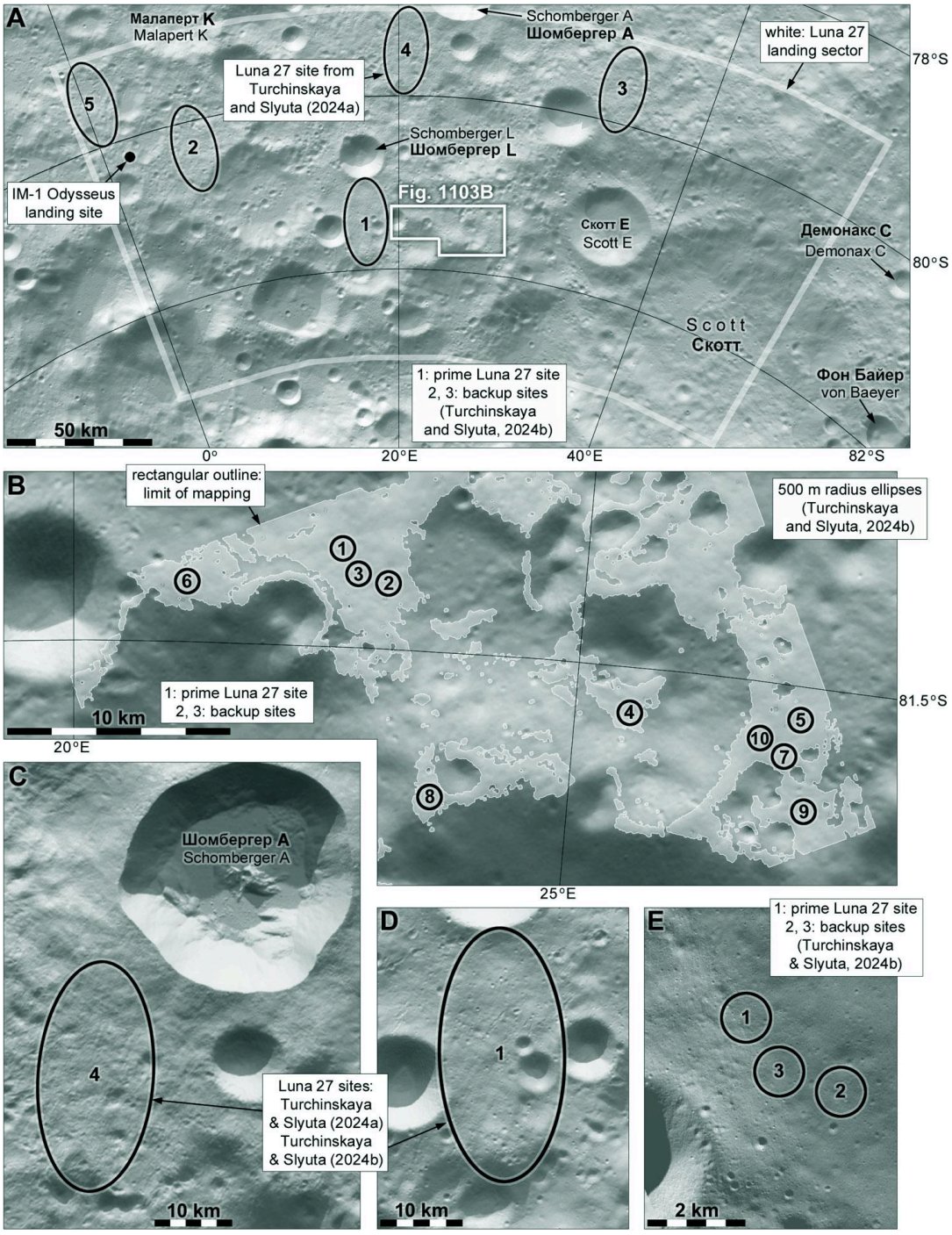
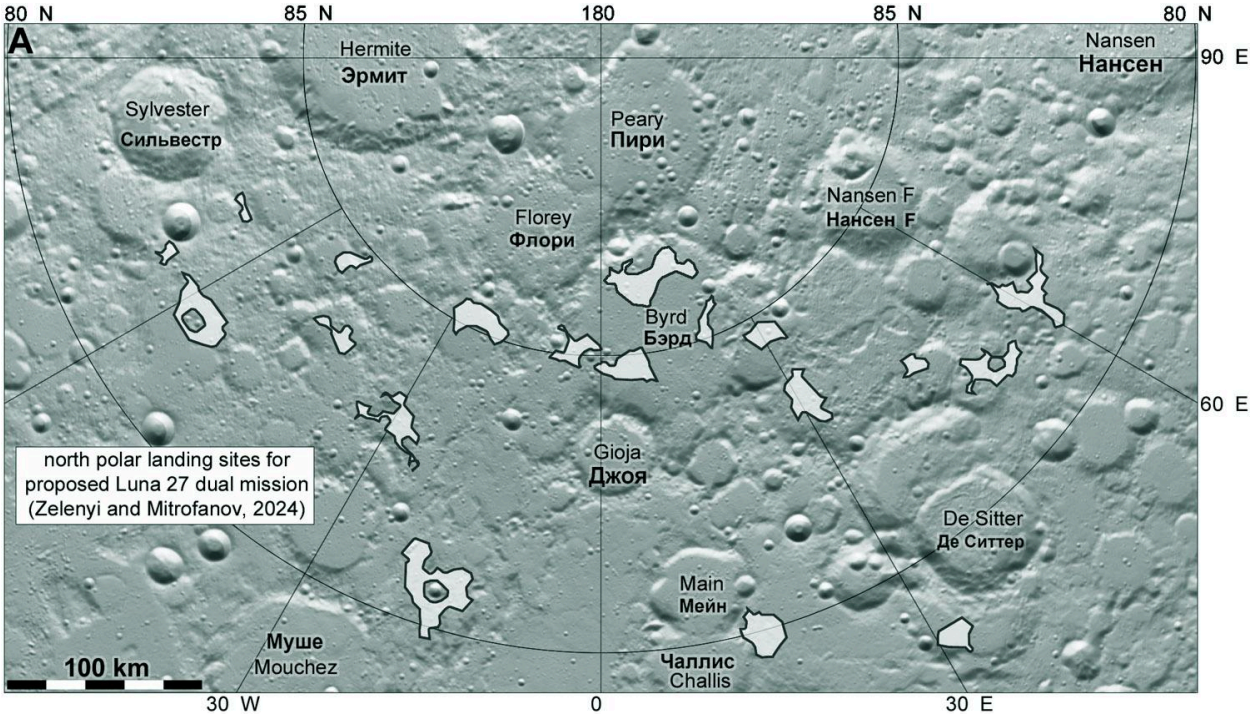


In 2024 different authors produced completely different results. This time, in an area with no sites in the previous study, we have 5 big ellipses and 10 small circles. The main map at top shows the large ellipses. A second map (middle) shows a small area in the middle of the previous map, with the 10 small circles. At bottom the preferred sites are enlarged.

May 19, 2025 - #moon #maps #luna27

The latest version of the Luna 27 mission involves two identical landers, so if one fails there is a second chance. If a south polar landing is successful the second lander could go to the north polar region. This map shows sites considered for this purpose, from a symposium in Moscow in October 2024. I'm not sure the second lander is approved but planning is proceeding.



Possible north polar landing sites from a 2024 presentation in Moscow. These may be used for a second Luna 27 lander if the first is successful in landing at the south pole. This dual lander version of the Luna 27 mission is being studied, but I am not sure it is approved yet.

May 19, 2025

With that I will end this look at Soviet and Russian lunar exploration. I hope you have found it interesting, and perhaps found something new in it. Tomorrow I will start a new topic, and I think it's time to go back to Mars. Later in the year I will do a special sequence looking at the recent moon landers.